Operation and Development of Mesoscale NWP System in HKO using JMA-NHM

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WMO VCP Training Workshop on the Latest Development on the Use and Interpretation of NWP Models

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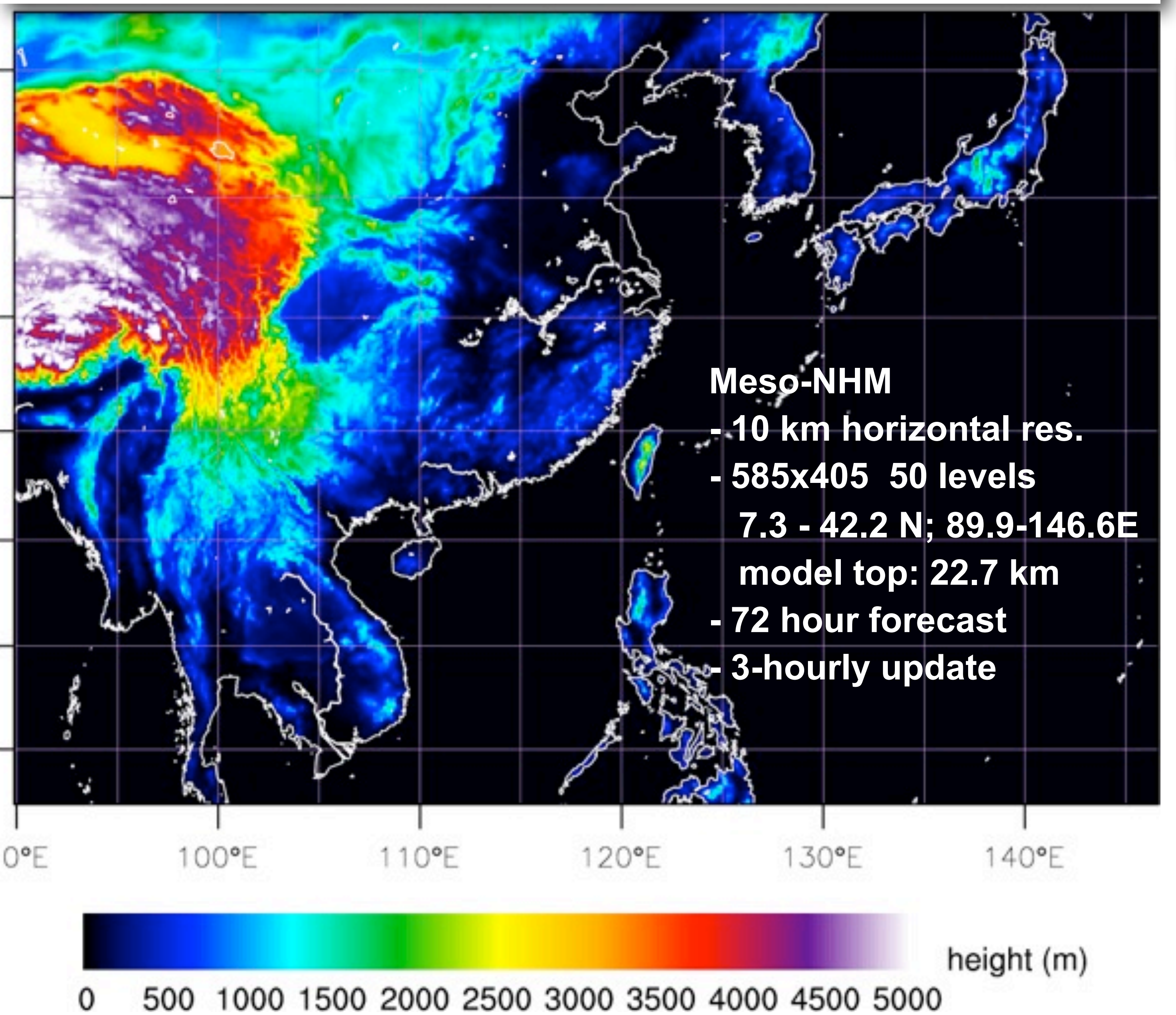
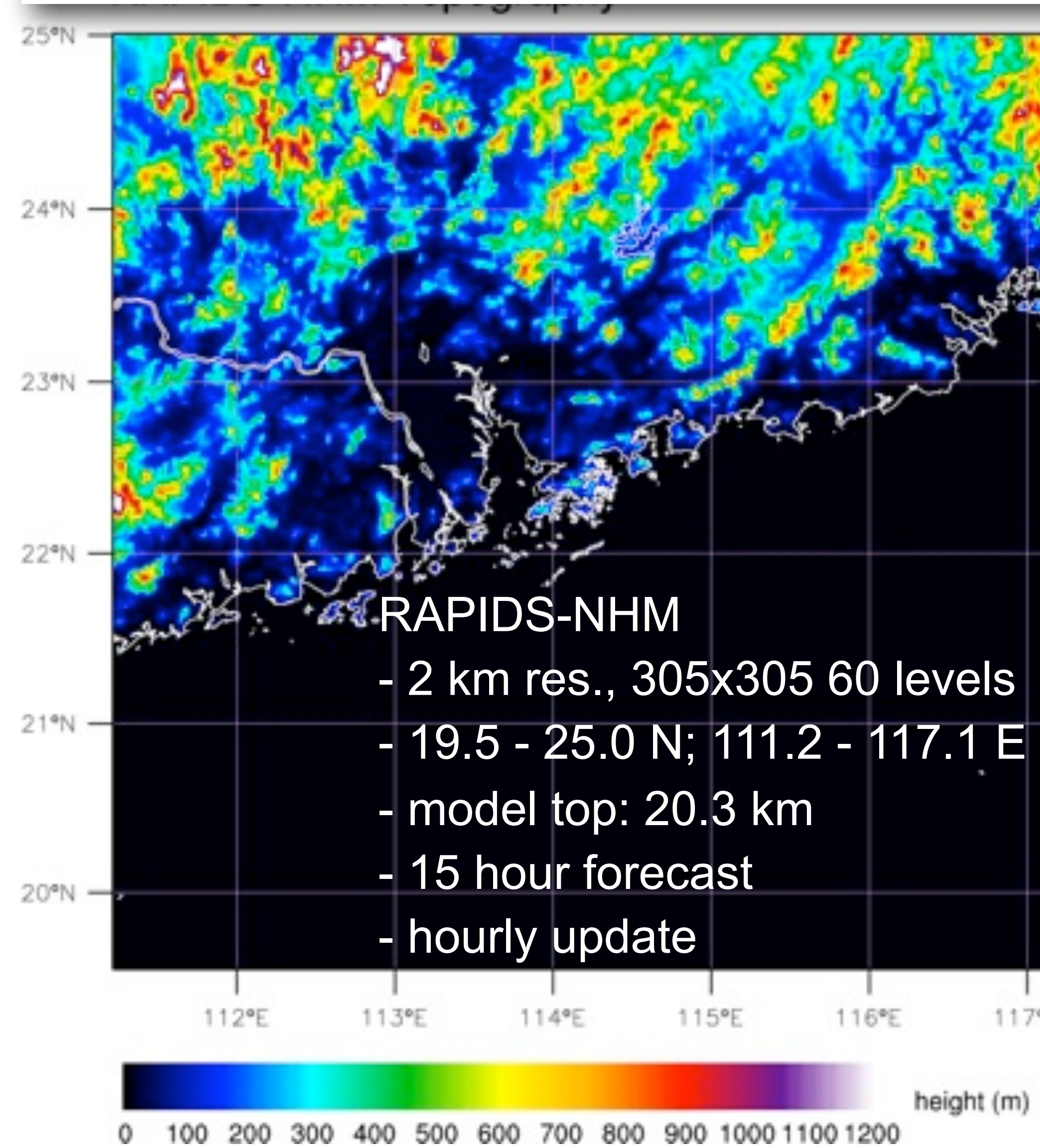
HONG KONG OBSERVATORY

Atmospheric Integrated Rapid-cycle (AIR) Model System based on JMA-NHM

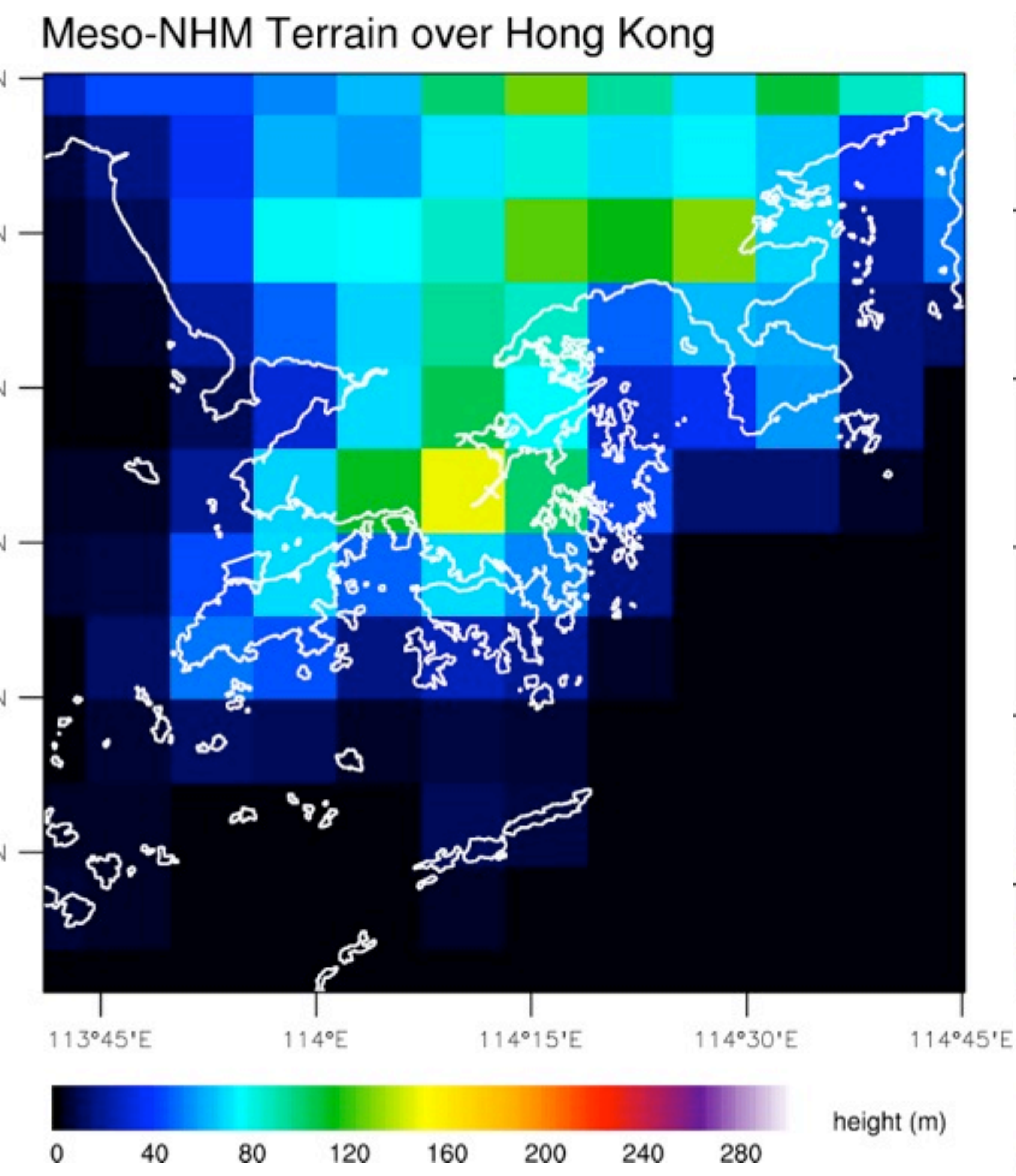
Meso-NHM

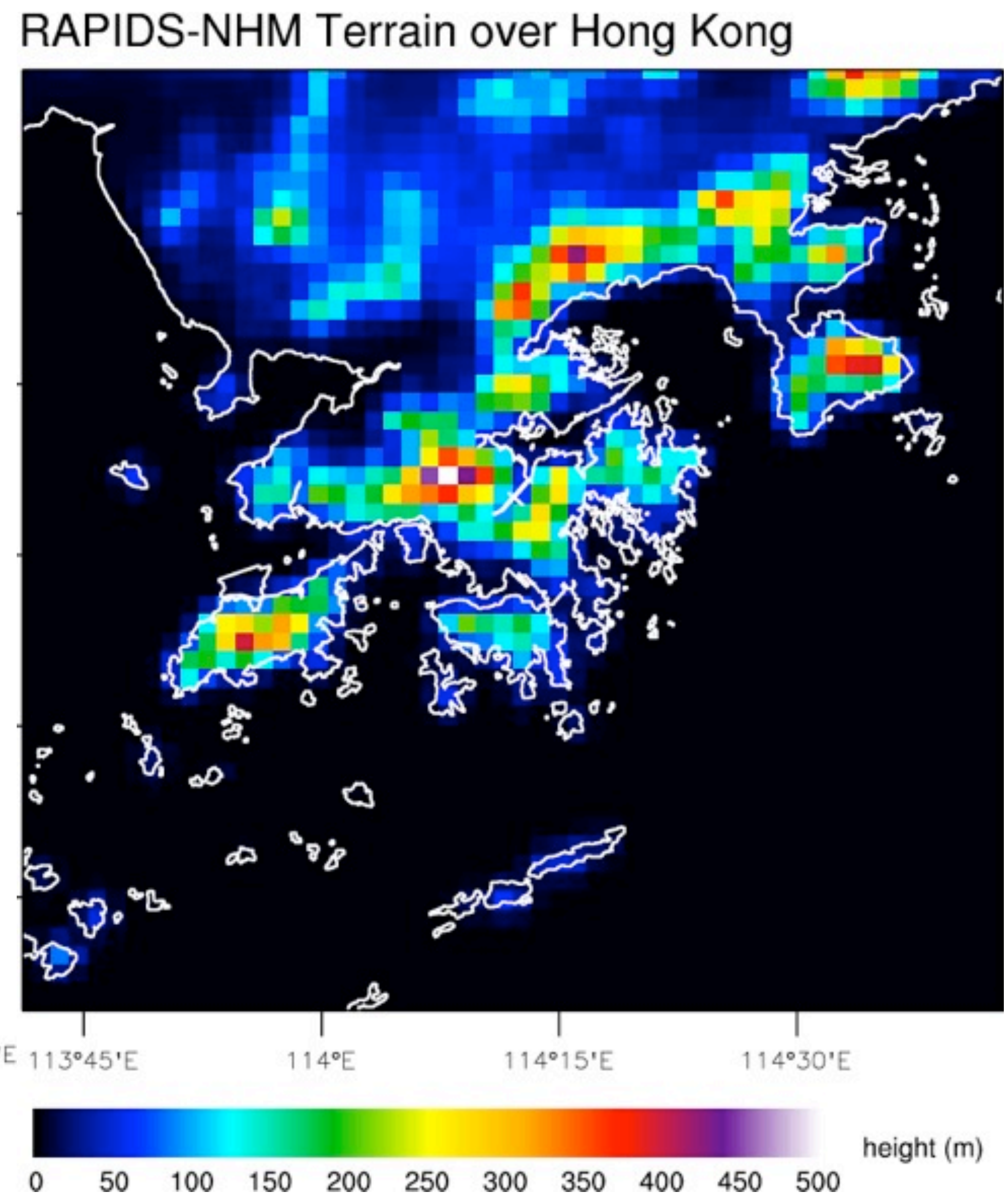


RAPIDS-NHM



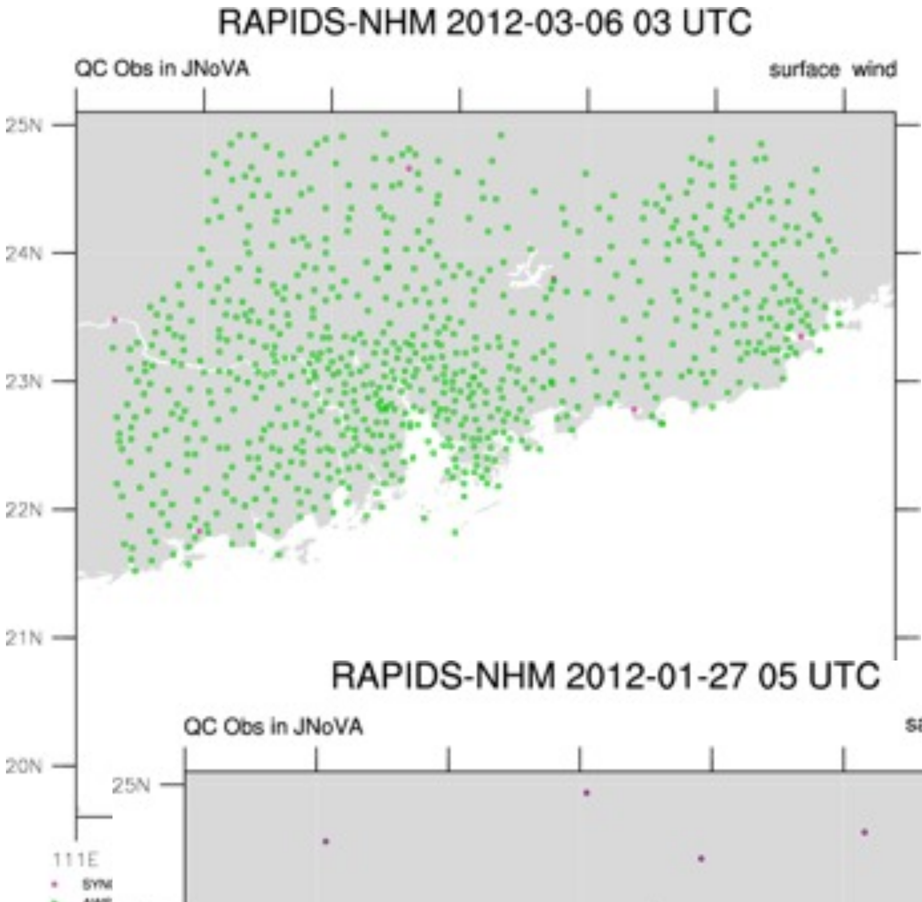
Model Terrain over Hong Kong

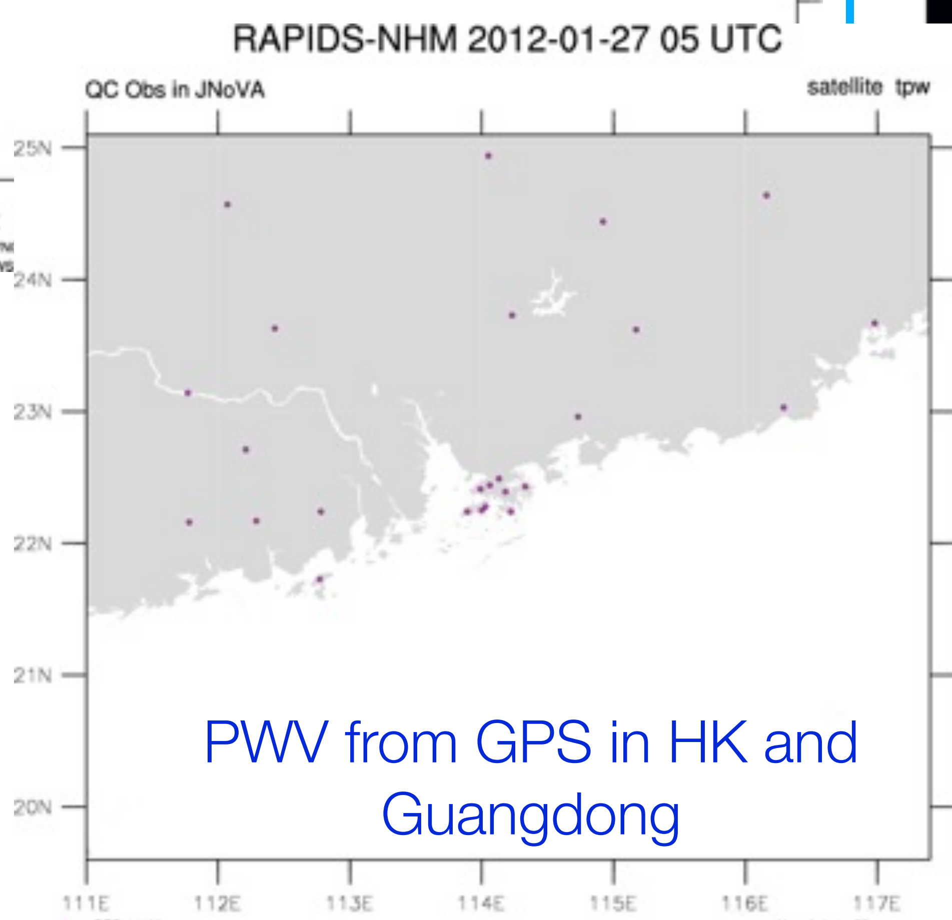




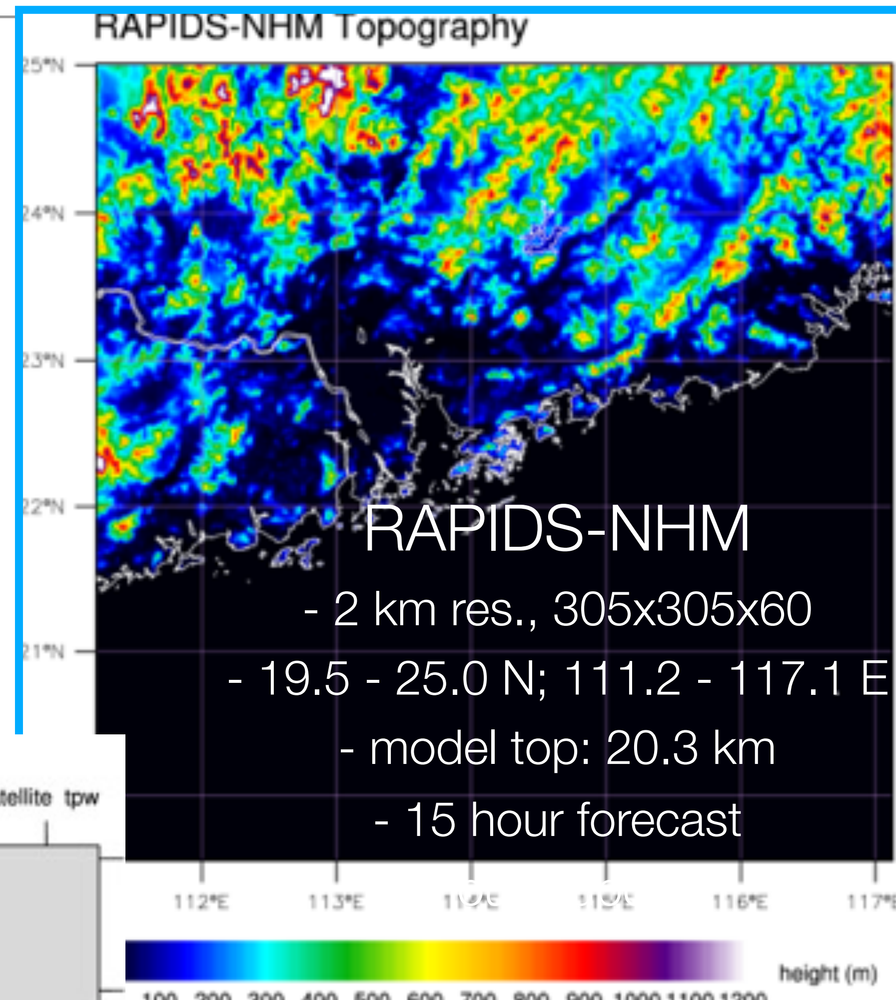
Data assimilation of observations from mesoscale observing network and remote sensing platforms

Surface observations from HK and Guangdong AWS network

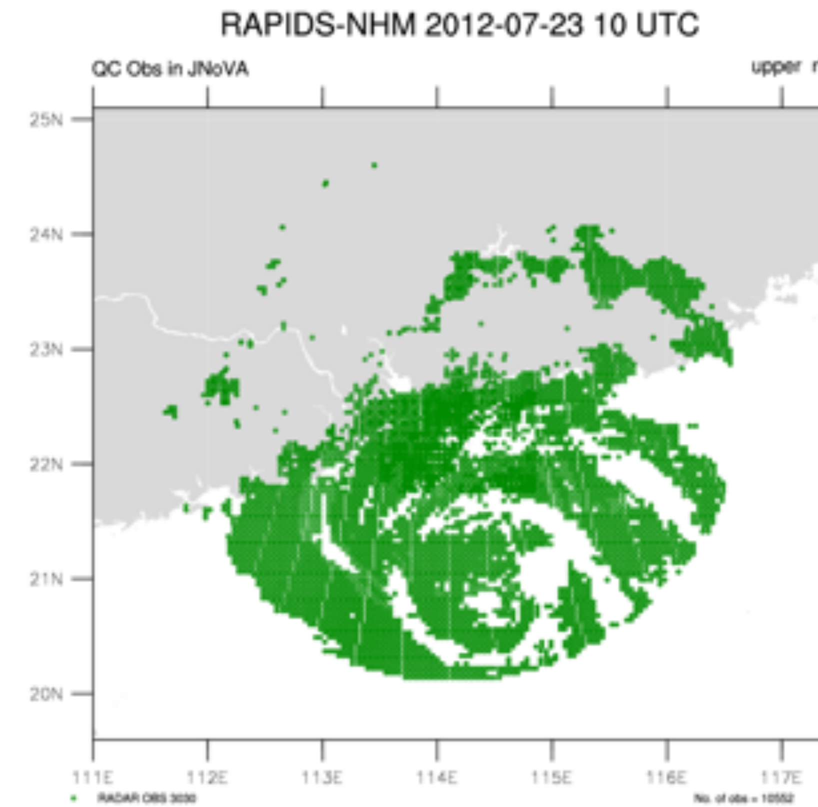


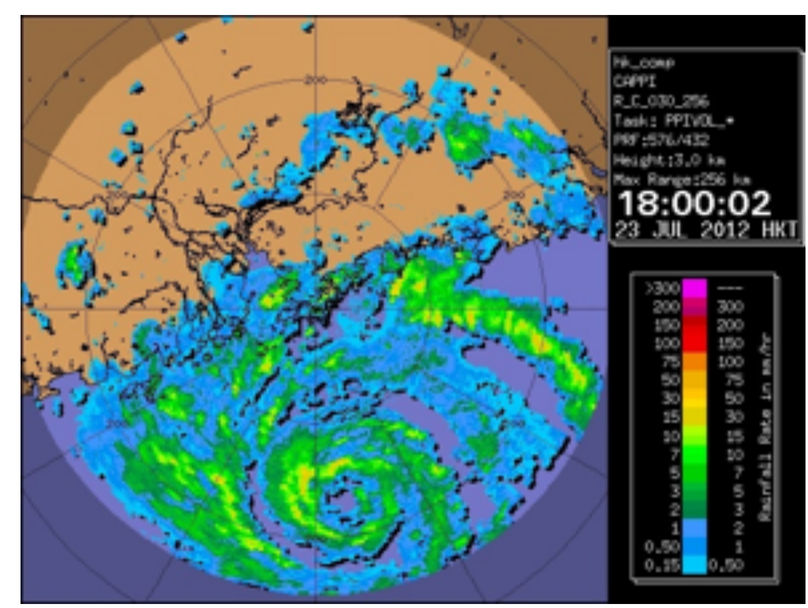


PWV from GPS in HK and Guangdong



Doppler wind and retrieval wind data from HK and GD radars





Storm resolving NWP

2 km resolution RAPIDS-NHM

3DVAR analysis

Hourly update

Targets of AIR/NHM

- Mesoscale analysis
- Quantitative precipitation forecasts (QPF)
- Tropical Cyclones
  - Track and intensity
  - High wind areas
- Other applications
  - Aviation specific

Applications

- Hourly mesoscale analysis based on RAPIDS-NHM 3DVAR

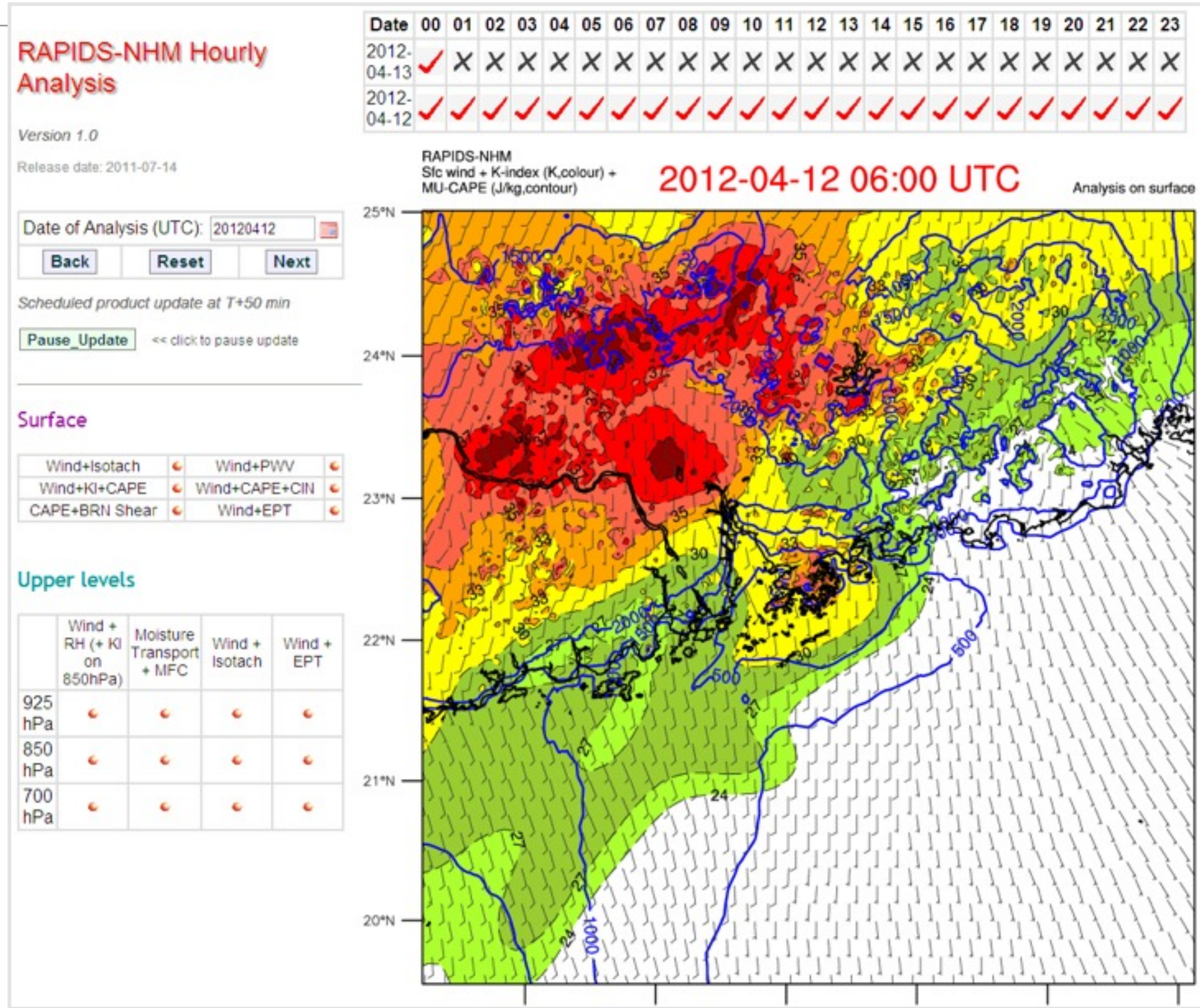
- A more optimal use of rapidly-update QPF from Meso-NHM and RAPIDS-NHM

- Forecasting of high wind in tropical cyclone situations

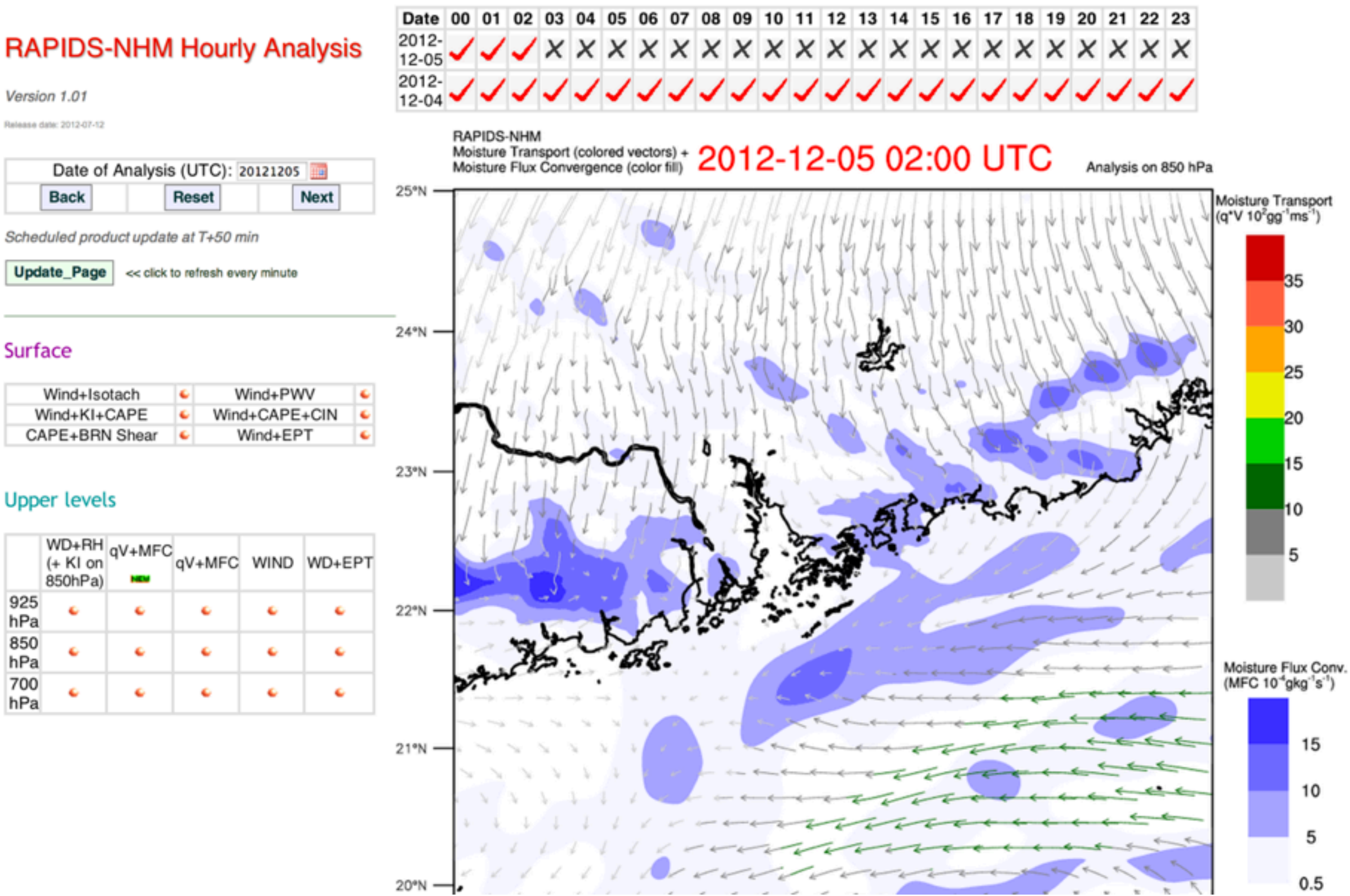
RAPIDS-NHM Hourly Analysis

Analysis products on surface and upper levels based on RAPIDS-NHM 3DVAR outputs

(horizontal resolution = 2 km)

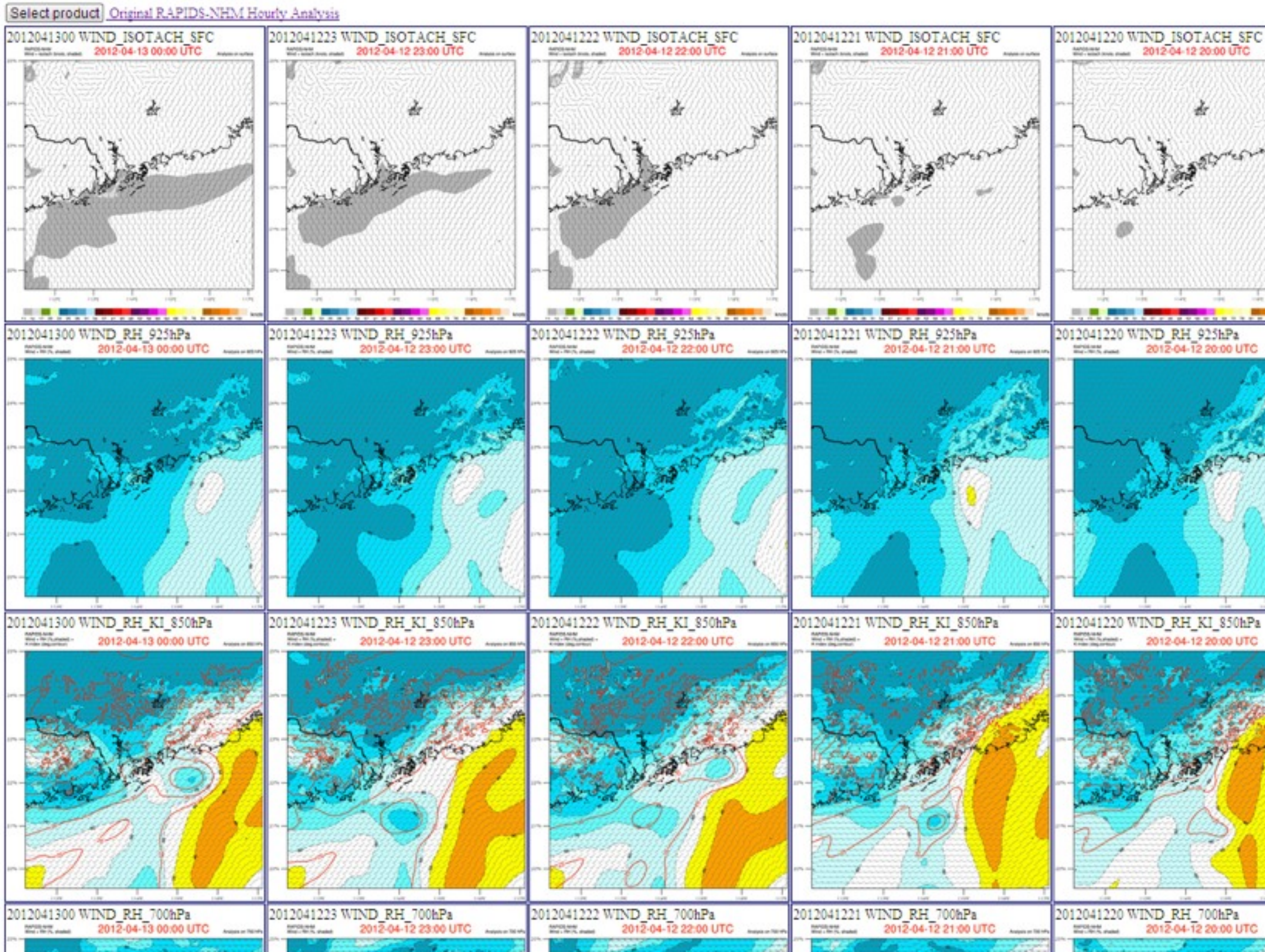


Moisture transport and moisture flux convergence analysis on 850 hPa

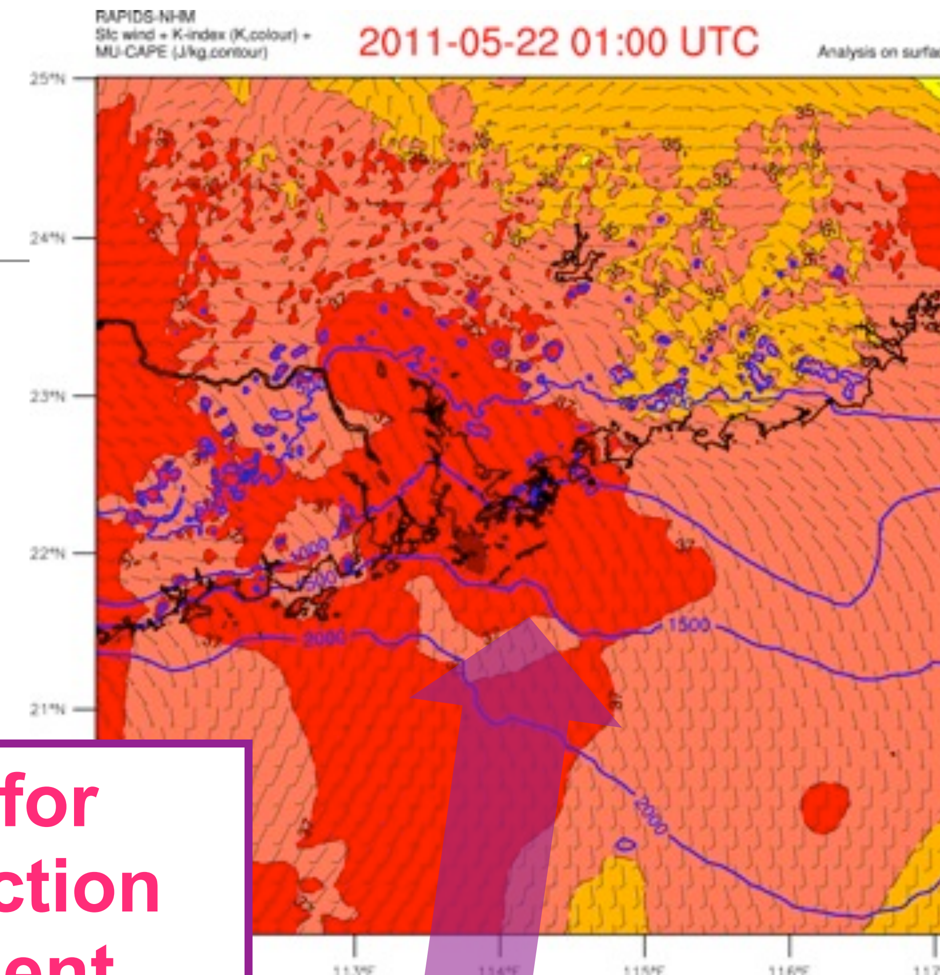


Stamp Map Display
showing the analysis over the last few hours

Rows of product display can be customized !

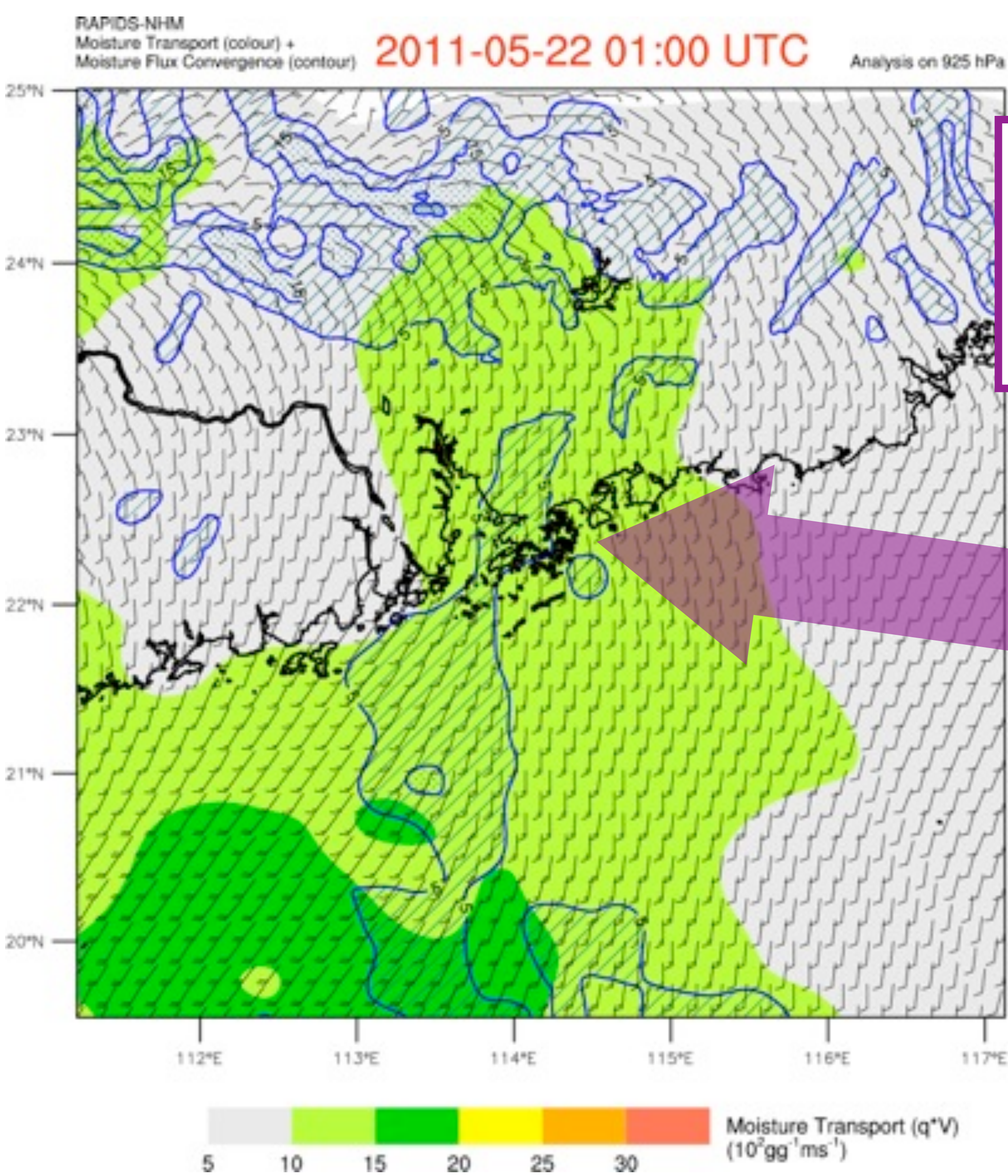


Instability indices
(K-index – color and CAPE - contour)

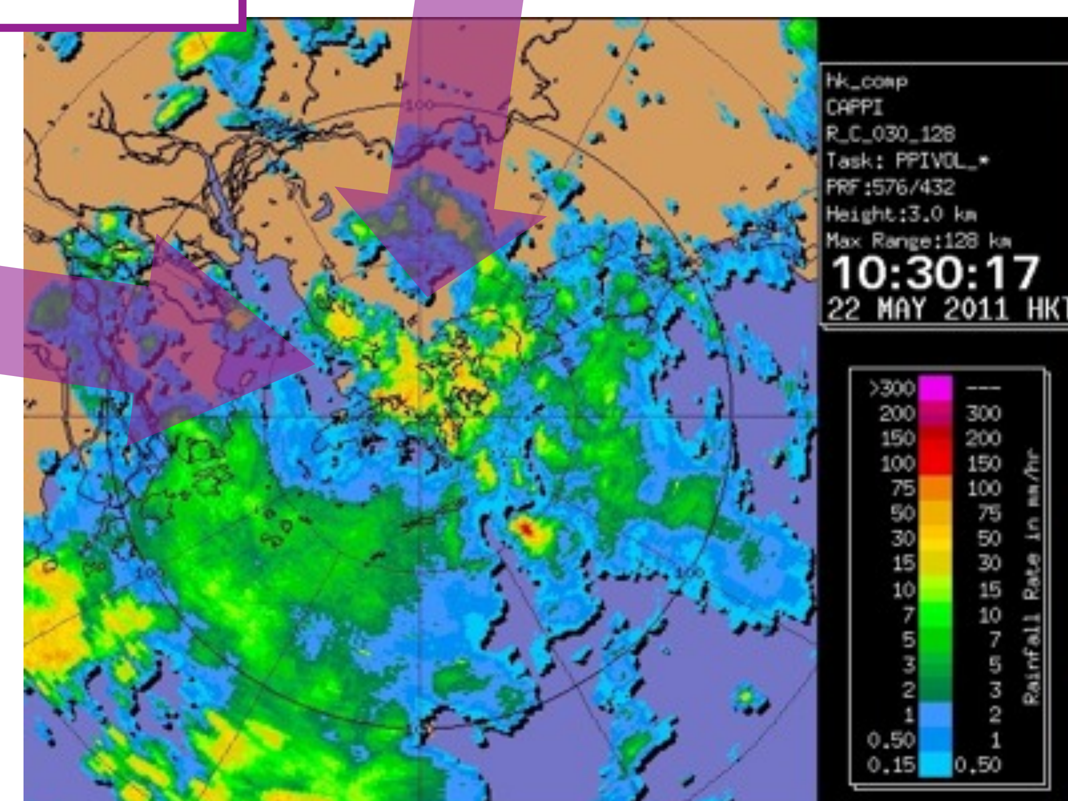


Hourly Meso-scale Analysis using RAPIDS-NHM

Moisture flux (q*V in color) and
Moisture flux convergence (hatched contour)



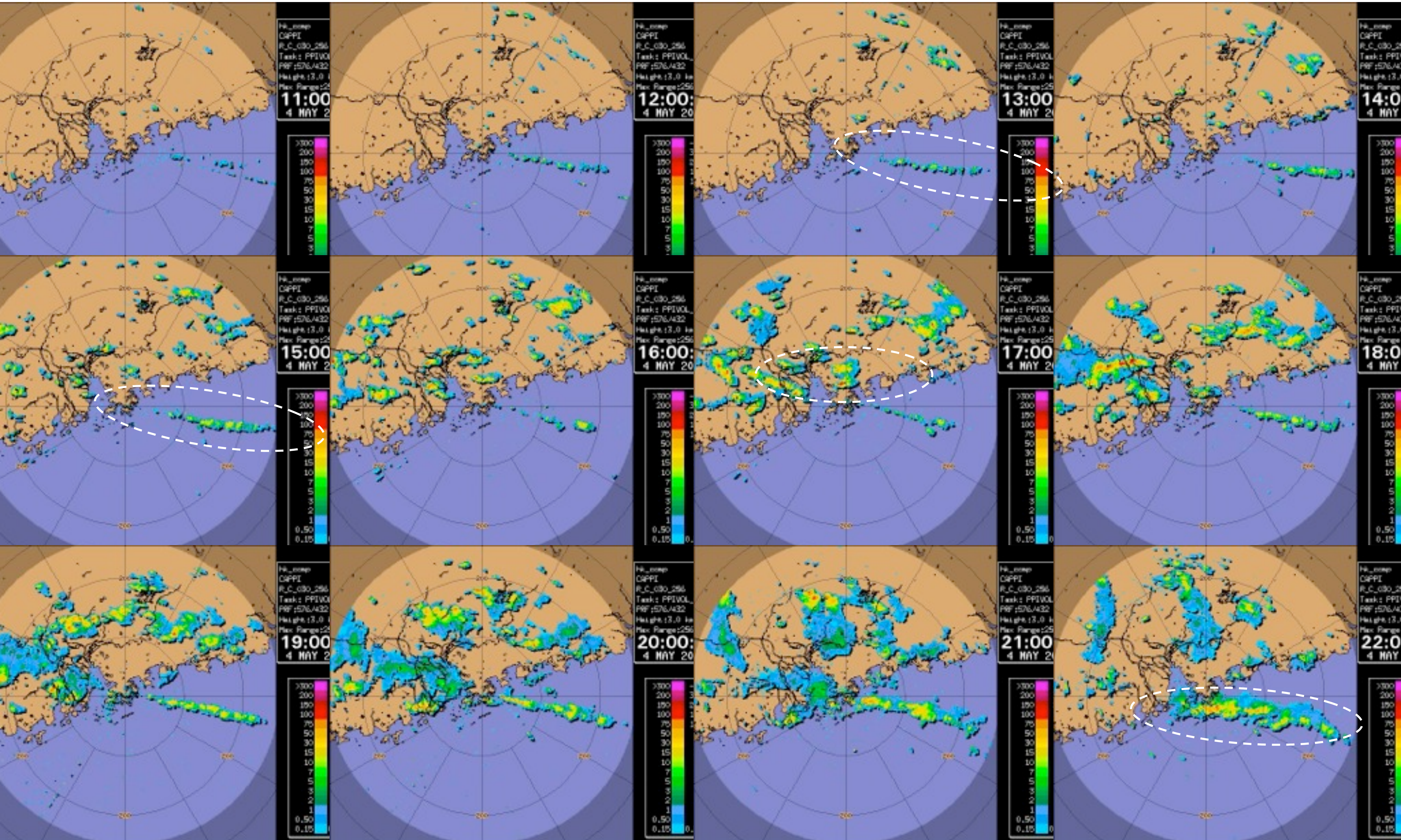
Potential for Sig. Convection Development

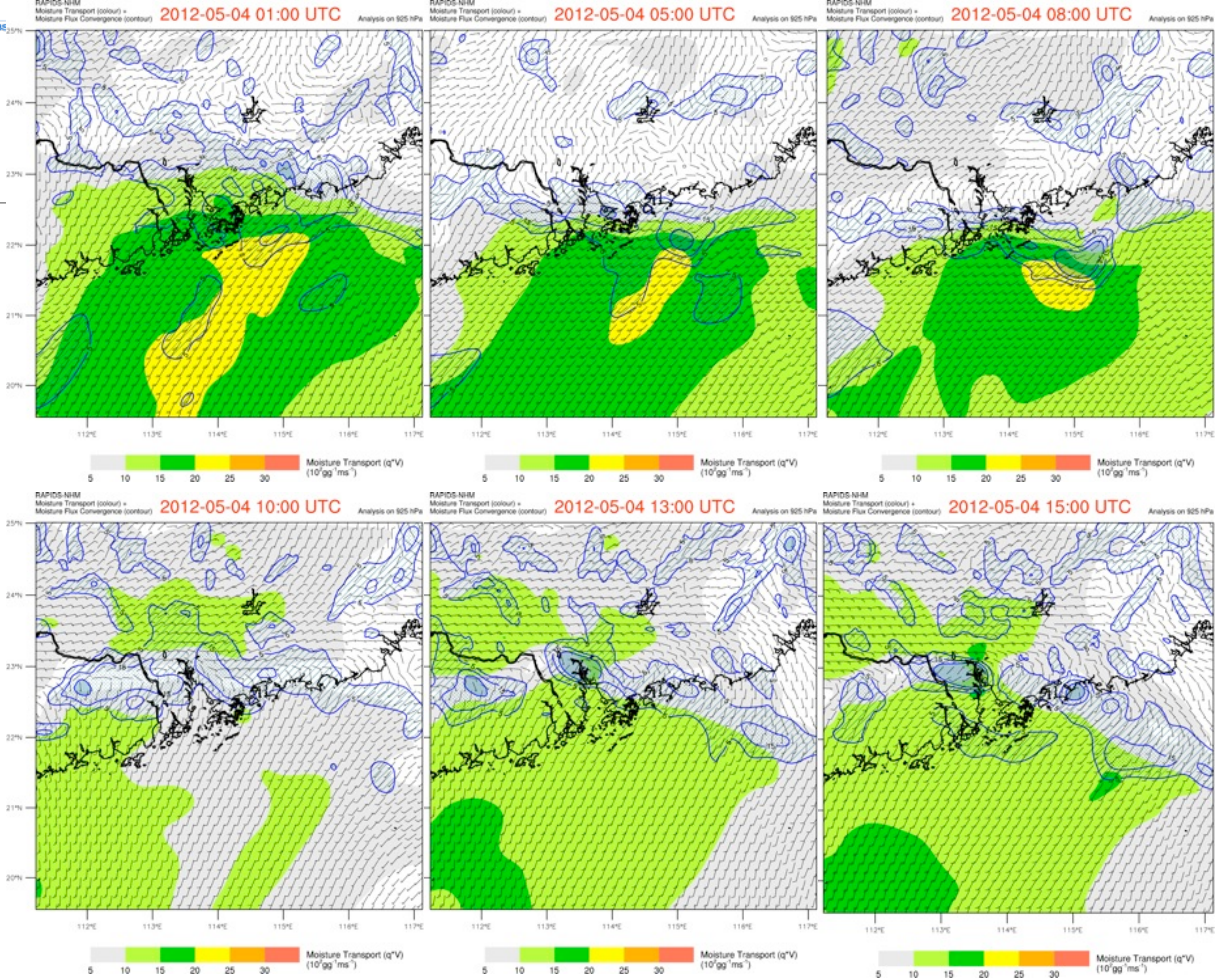


Stability indices

- K-index:
  - **K = T(850) + Td(850) - T(500) – [T-Td(700)]**
  - a measure of thunderstorm potential based on the vertical temperature lapse rate, including amount and vertical extent of low-level moisture in the atmosphere
- CAPE (Convective Available Potential Energy):
  - CAPE = g * Σ[(Tparcel - Tenv) / Tenv] dz
  - Summation is taken from level of free convection (LFC) to equilibrium level (EL)
  - amount of buoyant energy available to accelerate a parcel vertically
- CIN (Convective Inhibition):
  - basically an opposite of CAPE, and represents the -ve energy area on the sounding where the parcel temperature is cooler than that of the environment.
  - smaller (larger) the CIN is, the weaker (stronger) must be the amount of synoptic and mesoscale forced lift to bring the parcel to its LFC
- Further reference:
  - http://www.crh.noaa.gov/lmk/soo/docu/indices.php

Case (2012-05-04)




RAPIDS-NHM
Moisture Transport (colour) +
Moisture Flux Convergence (contour)
2012-05-04 01:00 UTC
Analysis on 925 hPa
2012-05-04 05:00 UTC
2012-05-04 08:00 UTC
2012-05-04 10:00 UTC
2012-05-04 13:00 UTC
2012-05-04 15:00 UTC
Moisture Transport (q*V)
(10²gg⁻¹ms⁻¹)
5 10 15 20 25 30

Moisture Flux Convergence (MFC) as a 'proxy' to inspect the source and change in moisture

- Moisture flux convergence (MFC)

$$\underbrace{\frac{\partial q}{\partial t}}_{\text{local rate of change of } q} + \underbrace{\nabla \cdot (q\mathbf{V}_h)}_{-\text{ horizontal MFC}} + \underbrace{\frac{\partial}{\partial p}(q\omega)}_{-\text{ vertical MFC}} = \underbrace{E - P}_{\text{sources and sinks}}$$

$$\text{MFC} = \underbrace{-u\frac{\partial q}{\partial x} - v\frac{\partial q}{\partial y}}_{\text{advection term}} \underbrace{-q\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right)}_{\text{convergence term}}$$

synoptic scale precipitation amount P can be estimated from:

$$\overline{P} \approx -\frac{1}{g}\int_0^{p_s} q\nabla \cdot \mathbf{V}_h \, dp$$

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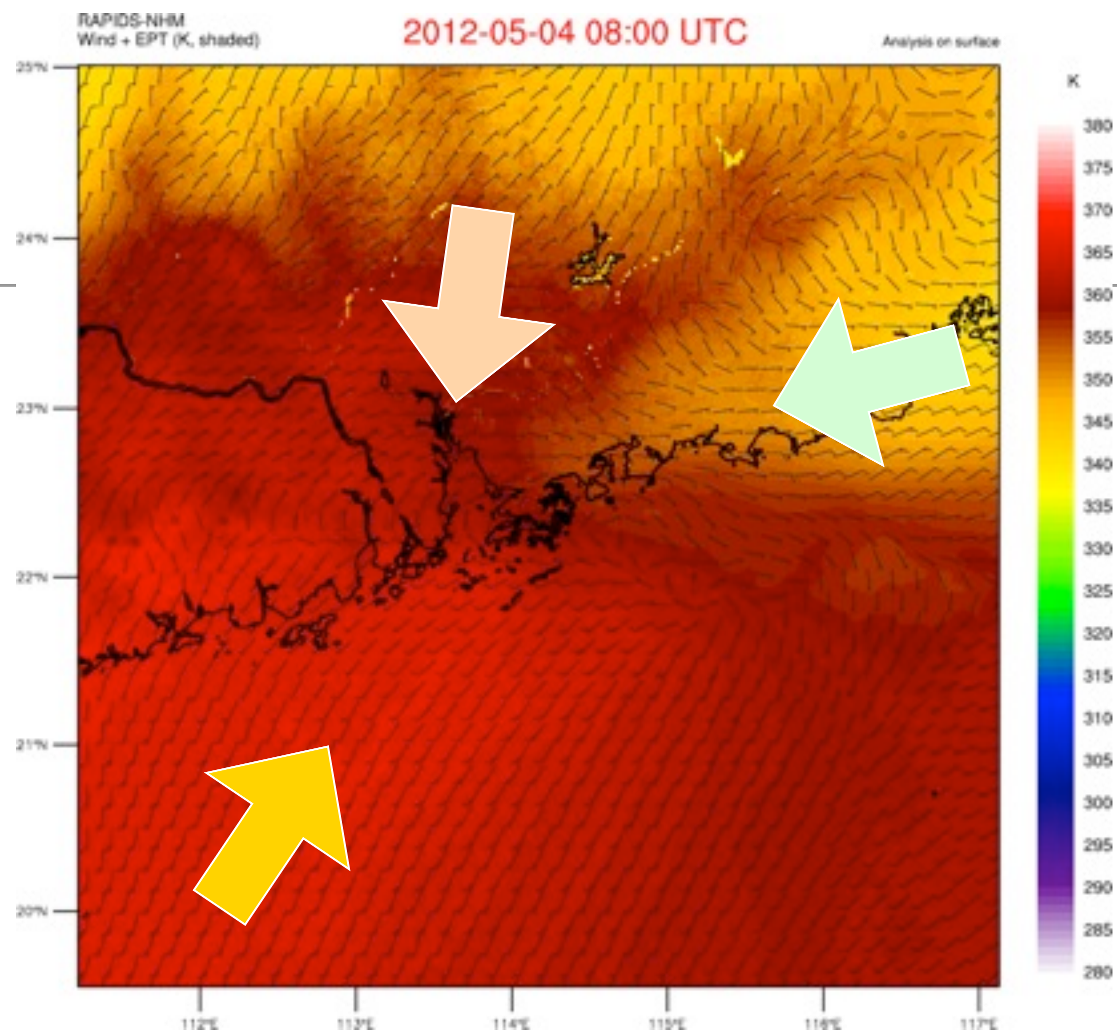
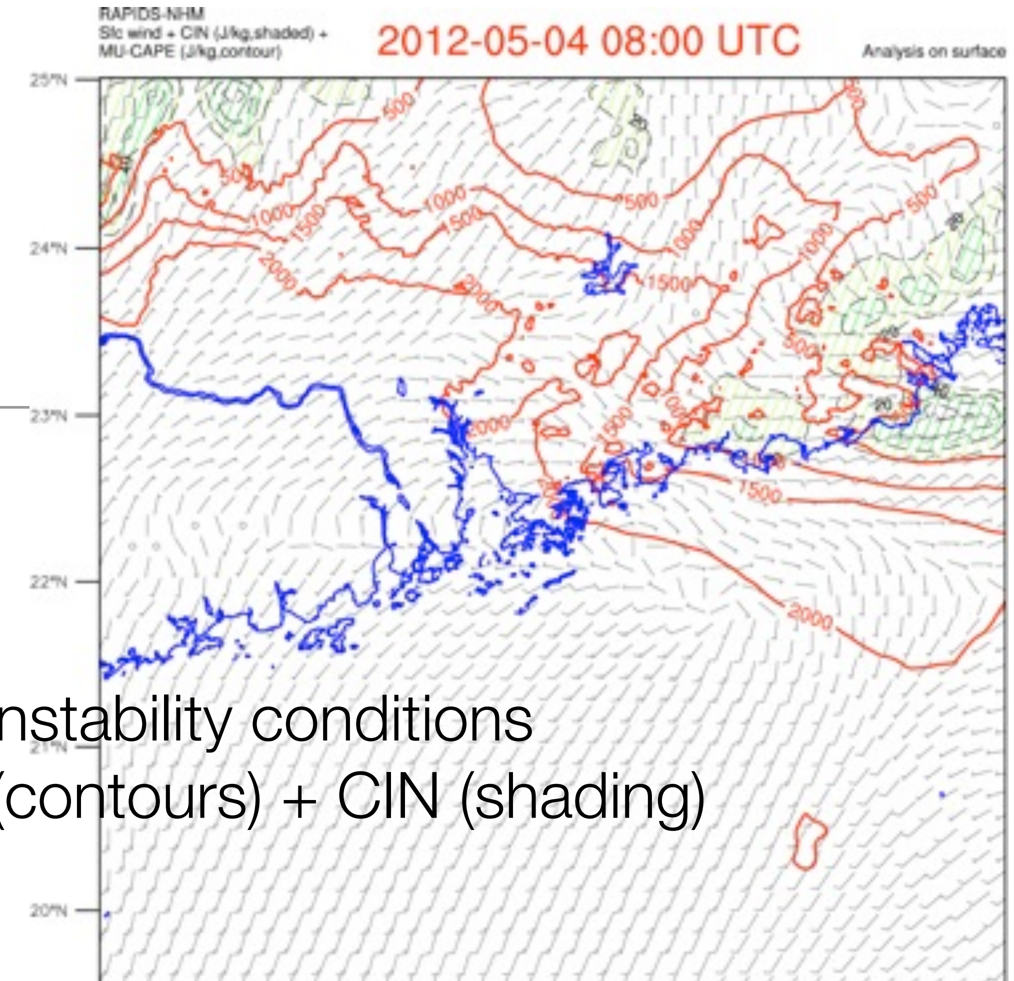
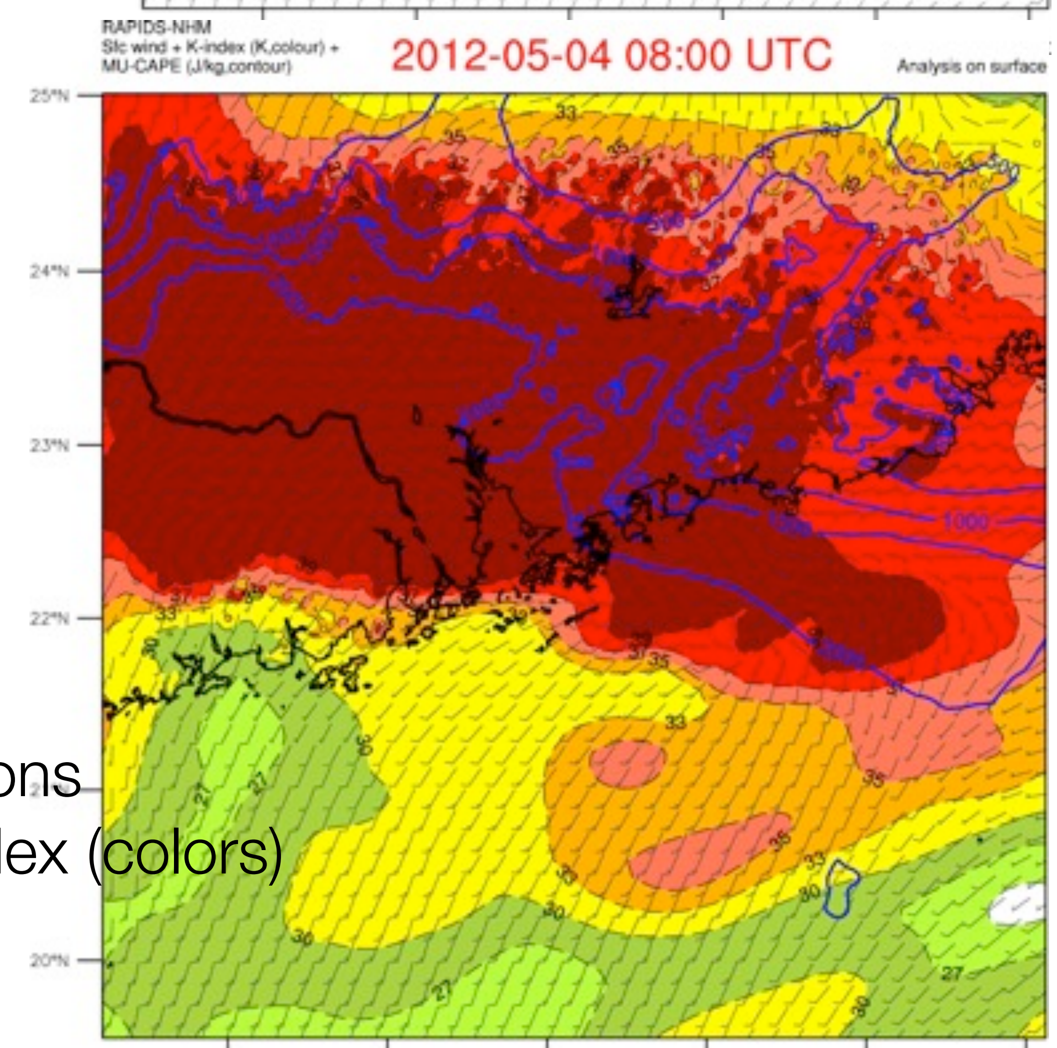


Surface θe (colors) showing boundaries of air masses

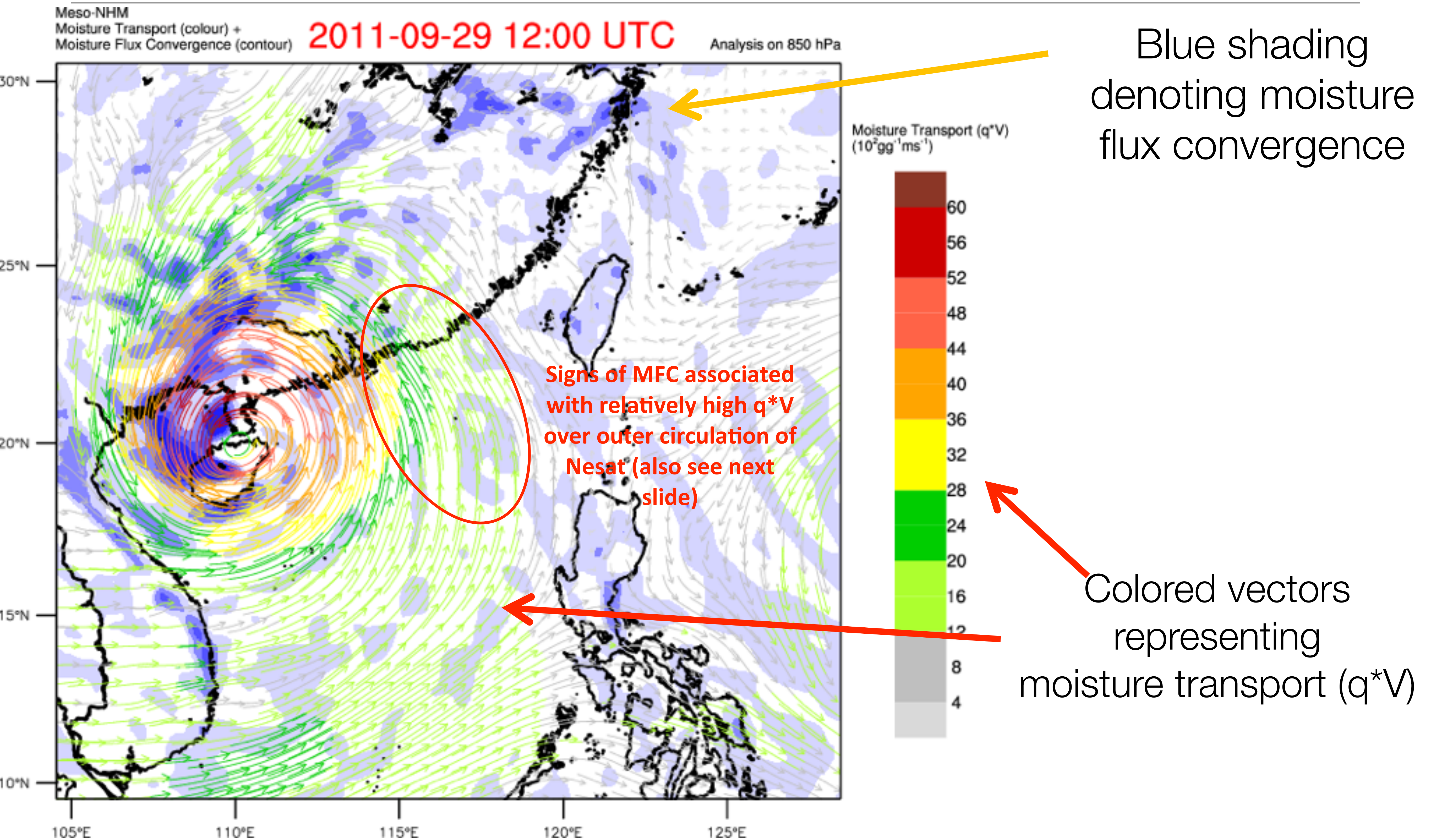


Instability conditions
CAPE (contours) + CIN (shading)



Instability conditions
CAPE (contours) + K-index (colors)

Moisture Transport and Flux Convergence in tropical cyclone case



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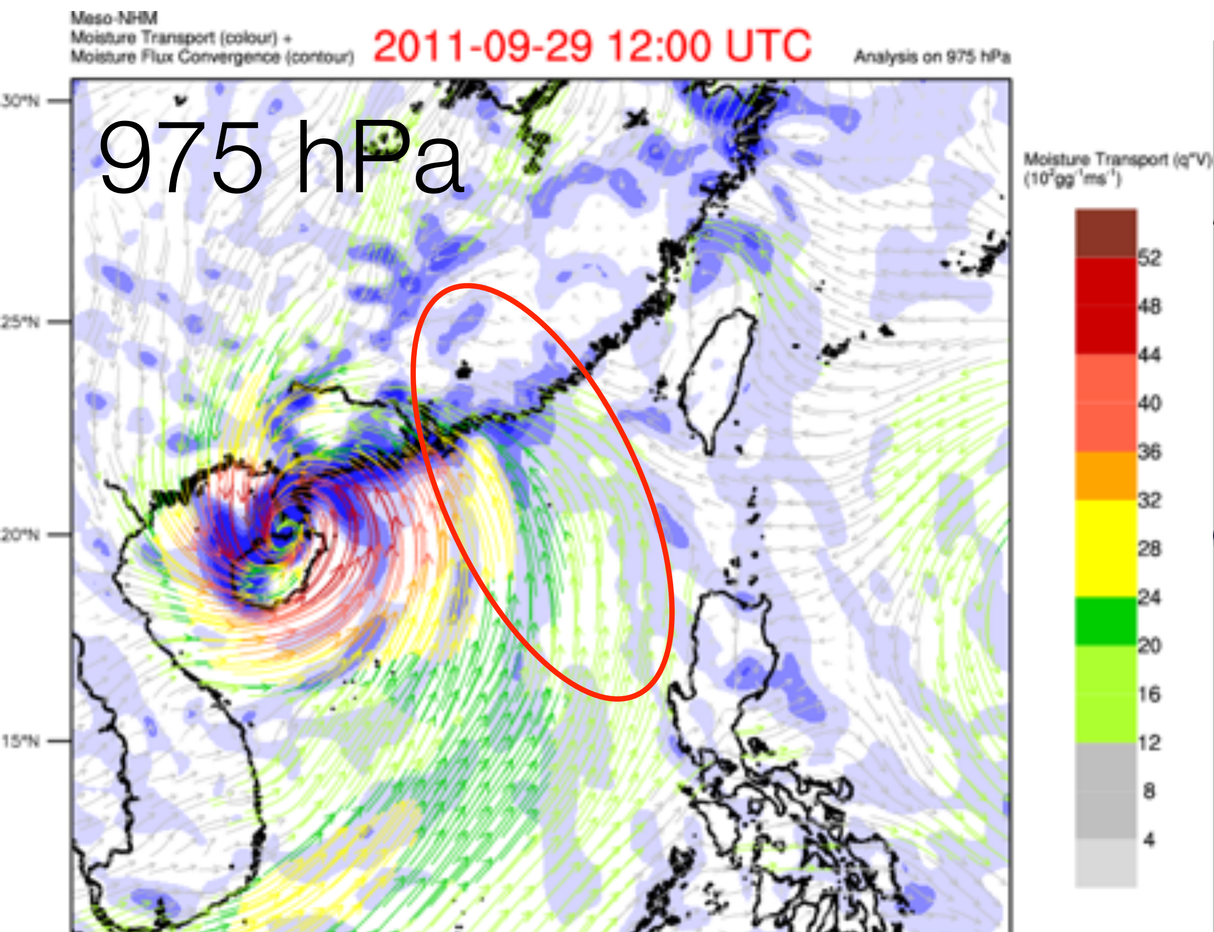
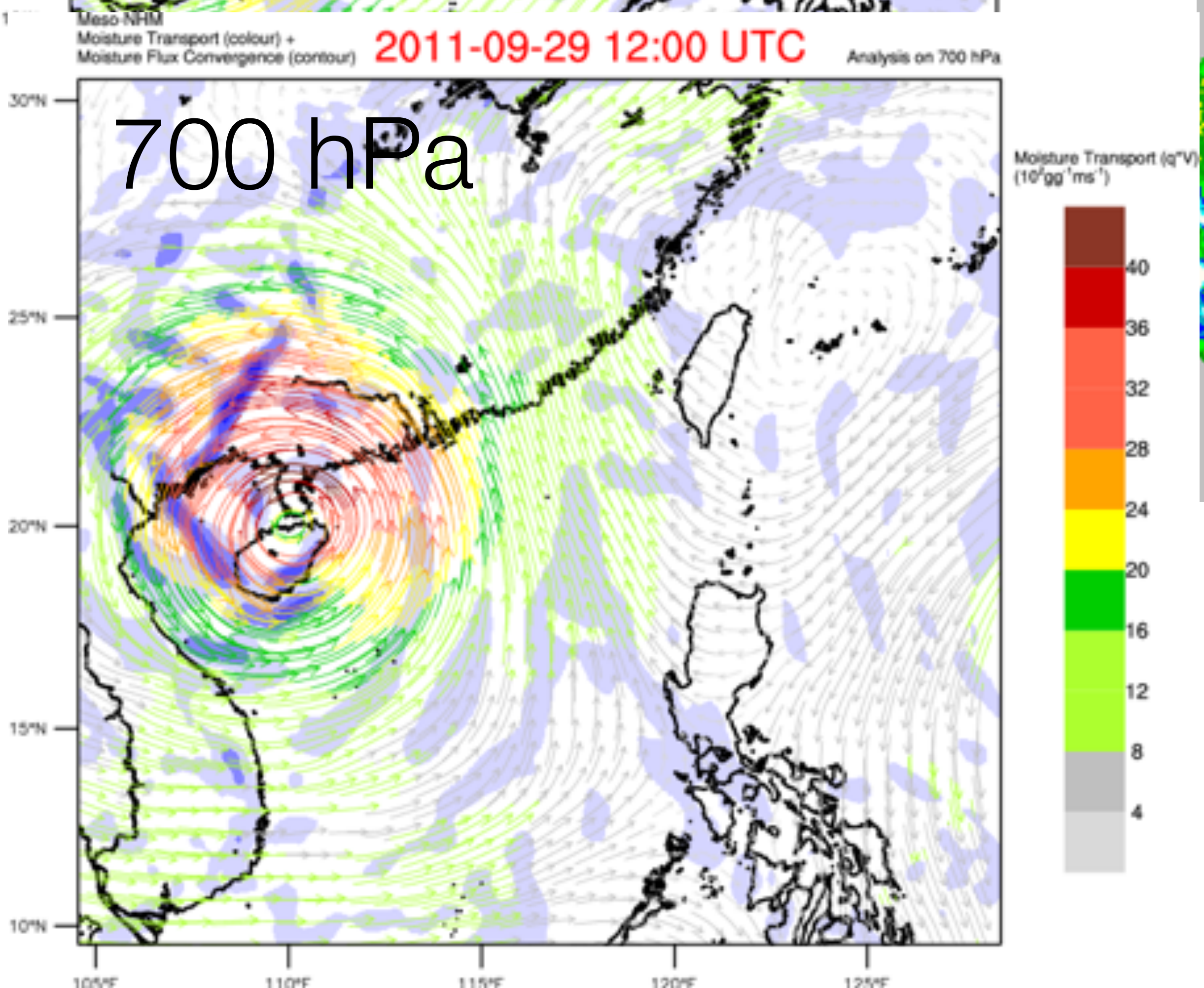
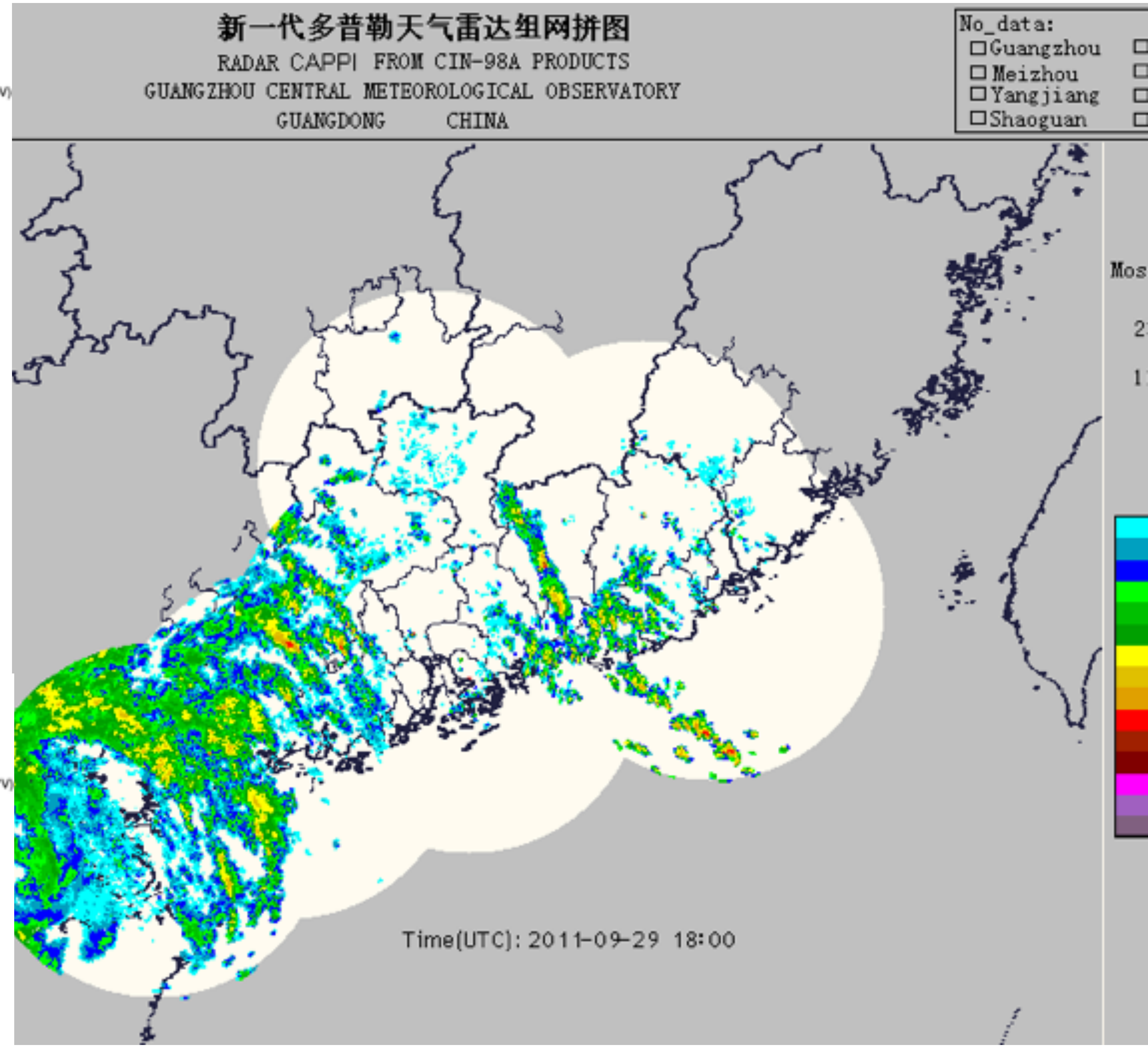
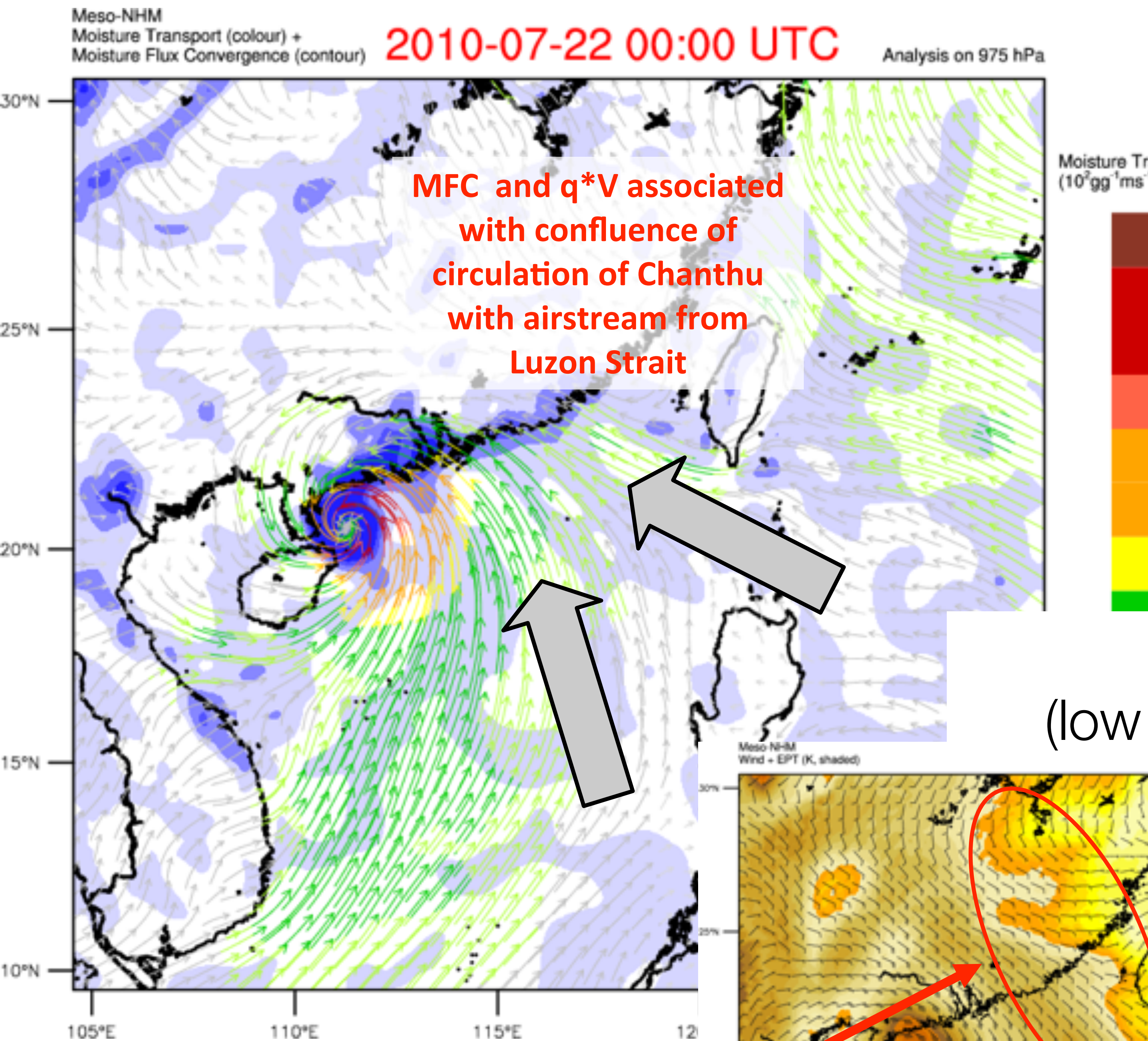
2011-09-29 18:00 UTC



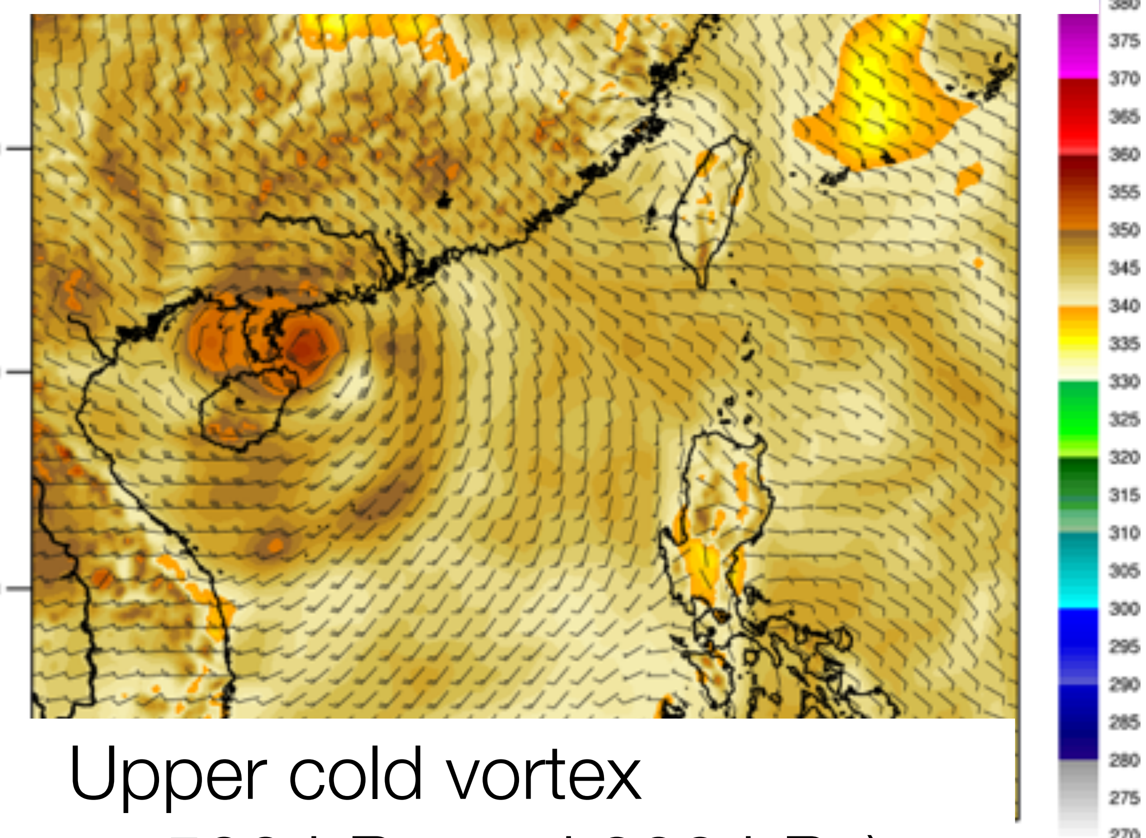




Chanthu (re-visited)

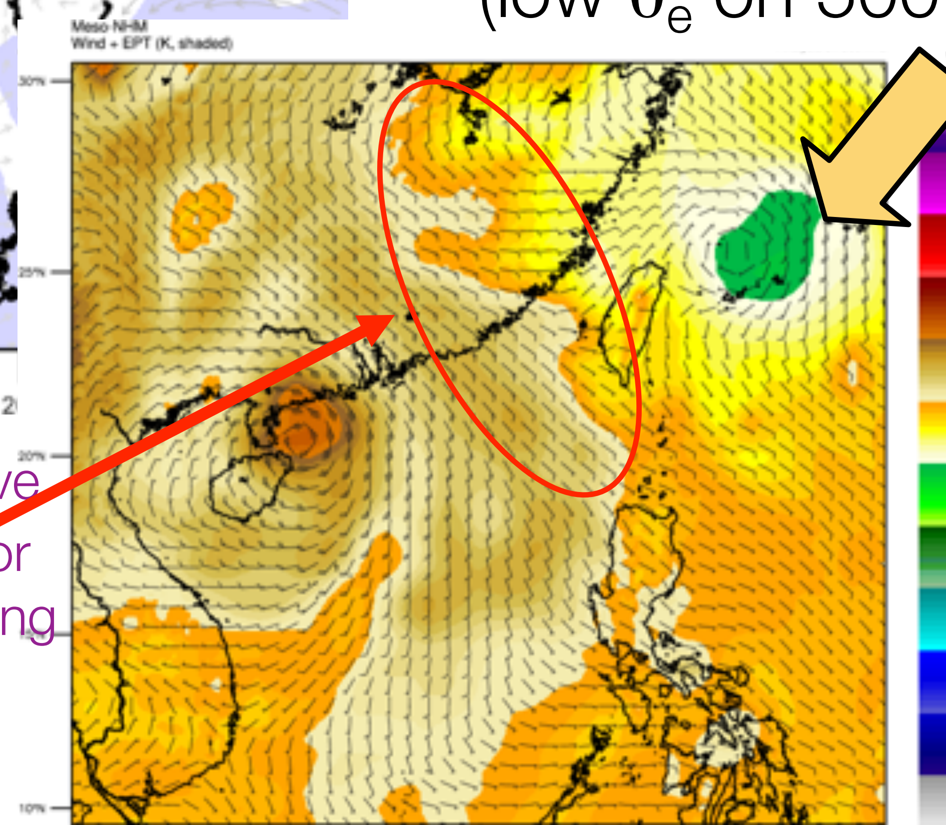


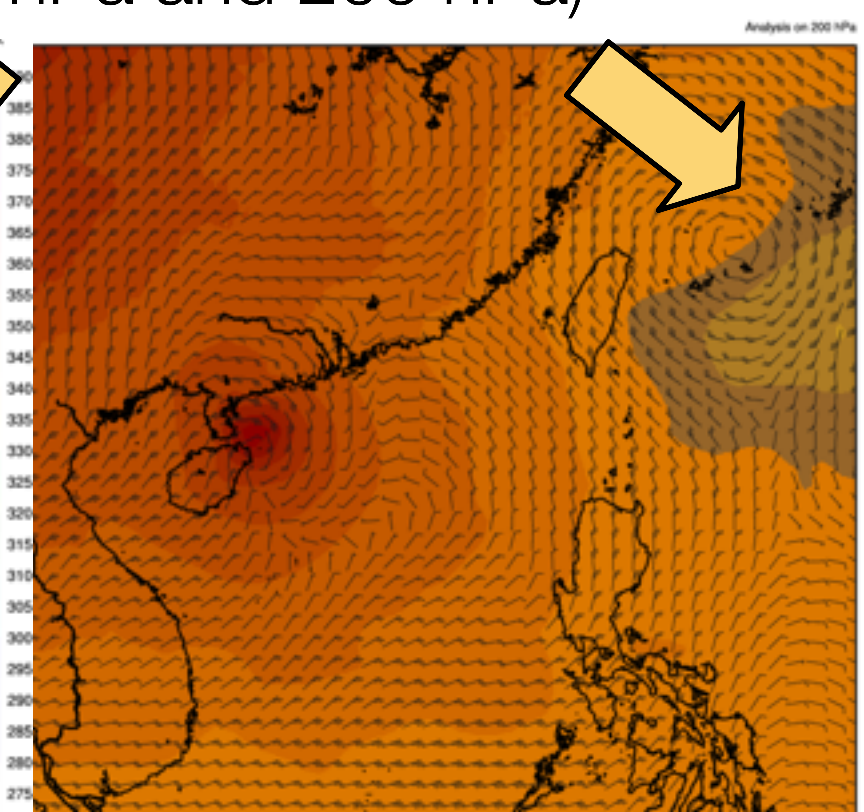
Equivalent potential temperature (θ_e) on 850 hPa



Upper cold vortex

(low θ_e on 500 hPa and 200 hPa)



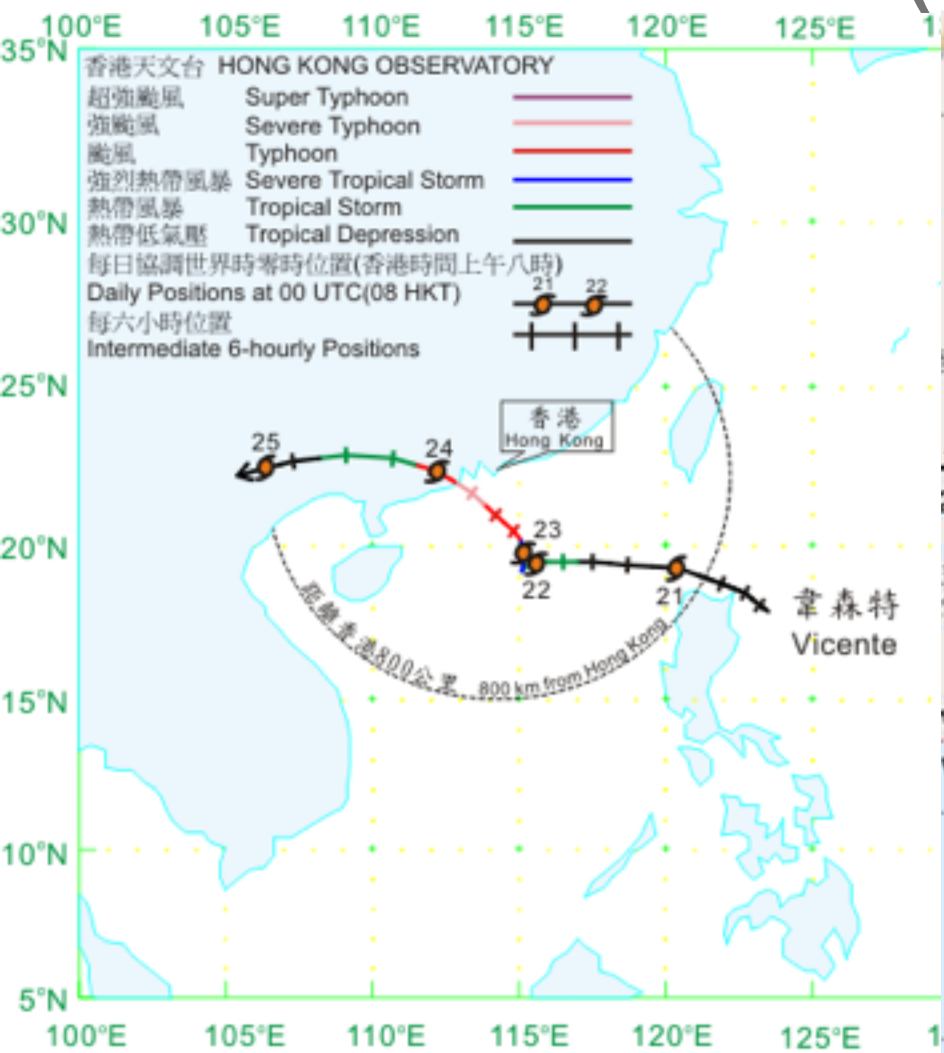


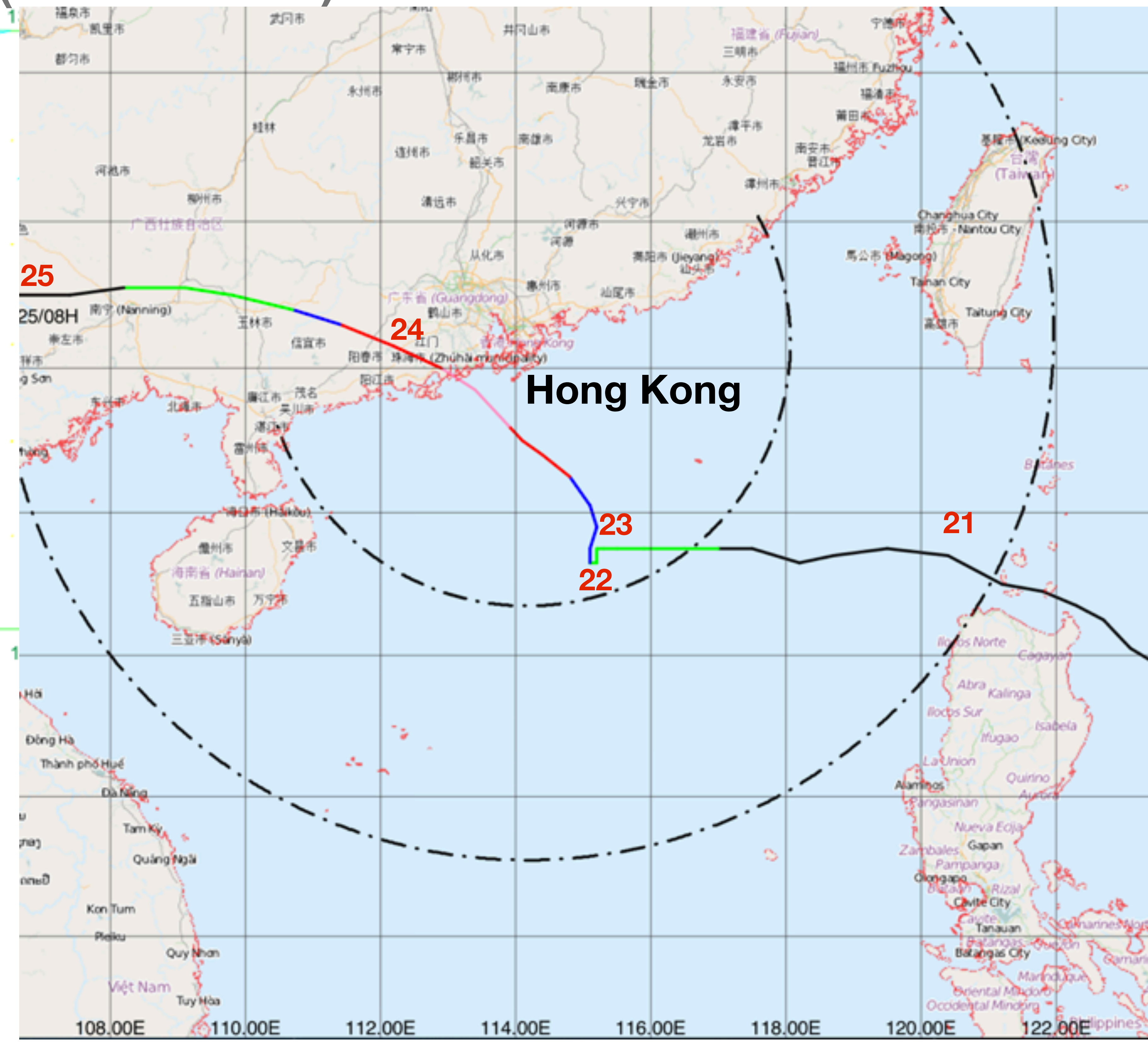
Lower θ_e aloft enhanced convective instability and a favorable factor for intense rainband development during the day on 22 July 2010

NHM in TC forecasting

Severe Typhoon Vicente
20-25 July 2012

• ST Vicente (Jul 2012)





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A multi-model scenarios on daily rainfall Forecast from 2012-07-21 12 UTC

Quantitative Precipitation Forecast (QPF) Summary Table

Select Cycle Run

Year 2012
Month Jul
Day 21
UTC 12
- 12 hr
+ 12 hr

Day of F/C

Day 1
Day 2
Day 3
Day 4
Day 5
Day 6
Day 7

Table 1. Summary of QPF of Global Models for 23 Jul 2012 (MON)

Model	Product	Base Time		
		20/12 Z	21/00 Z	21/12 Z
Ensemble	Automatic Forecast	Showers (Moderate)	Showers (Moderate)	Showers (Moderate)
JMA	Automatic Forecast	Showers , heavy at first (Heavy)	Showers , heavy at first (Heavy)	Showers (Moderate)
	East grid	21 mm	29 mm	31 mm
	West grid	9 mm	14 mm	22 mm
ECMWF	Automatic Forecast	Showers (Moderate)	Showers , heavy later (Heavy)	Showers , heavy at first (Heavy)
	NW grid	5 mm	9 mm	19 mm
	SE grid	16 mm	28 mm	33 mm
NCEP	Grid Point (22 N,114 E)	N/A	N/A	N/A

global models and EPS

Table 2. Summary of Regional Models for 23 Jul 2012 (MON)

Model	Product	Base Time		
		21/06 Z	21/12 Z	21/18 Z
Meso-NHM	Time Series	31 mm	23 mm	45 mm
MPIRSM 60-km	Time Series	2 mm	12 mm	12 mm
MPIRSM 20-km	Time Series	N/A	6 mm	7 mm
MPIRSM 60-km TLE Mean	Time Series	6 mm	9 mm	10 mm
MPIRSM 20-km TLE Mean	Time Series	6 mm	8 mm	19 mm

regional models

Legend :

	No Rain
	Light Rain : < 5 mm
	Moderate Rain (Lower) : 5 mm - 10 mm
	Moderate Rain (Higher) : 10 mm - 25 mm
	Heavy Rain : > 25 mm

Actual Conditions on 23 Jul 2012 :

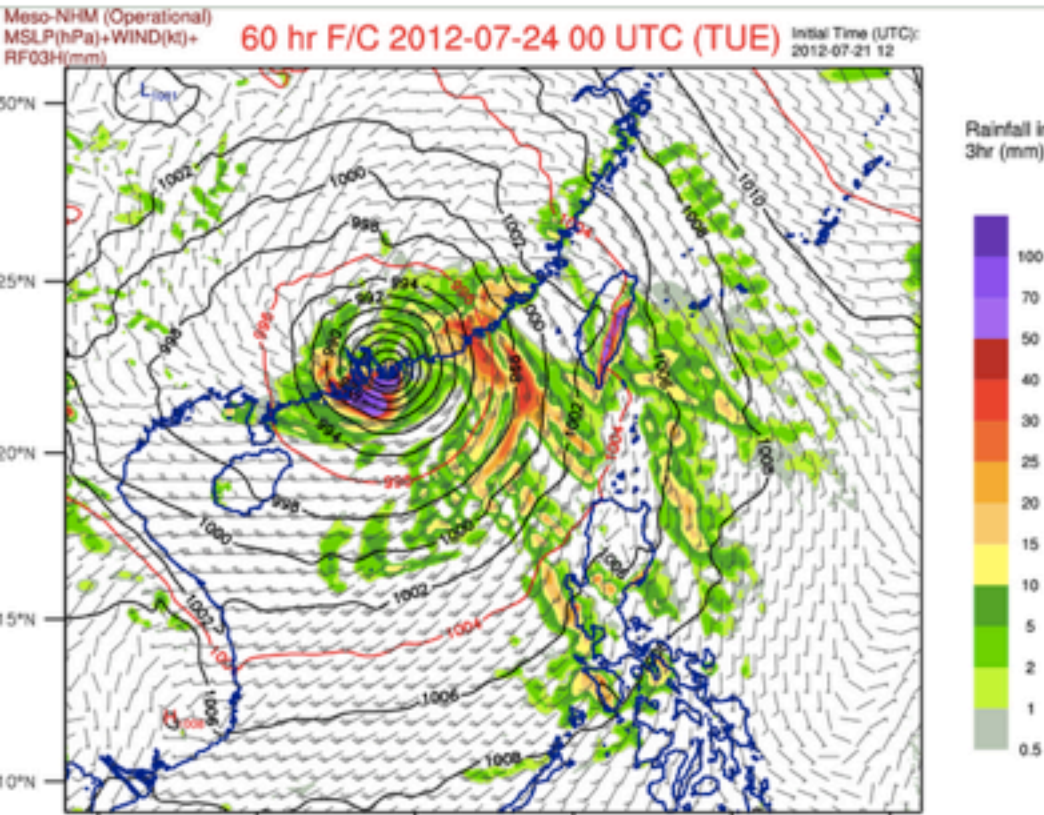
Total rainfall (HKO)	112.0 mm
Average rainfall of 7 FCV rain gauges	105.1 mm

time-lagged ensemble

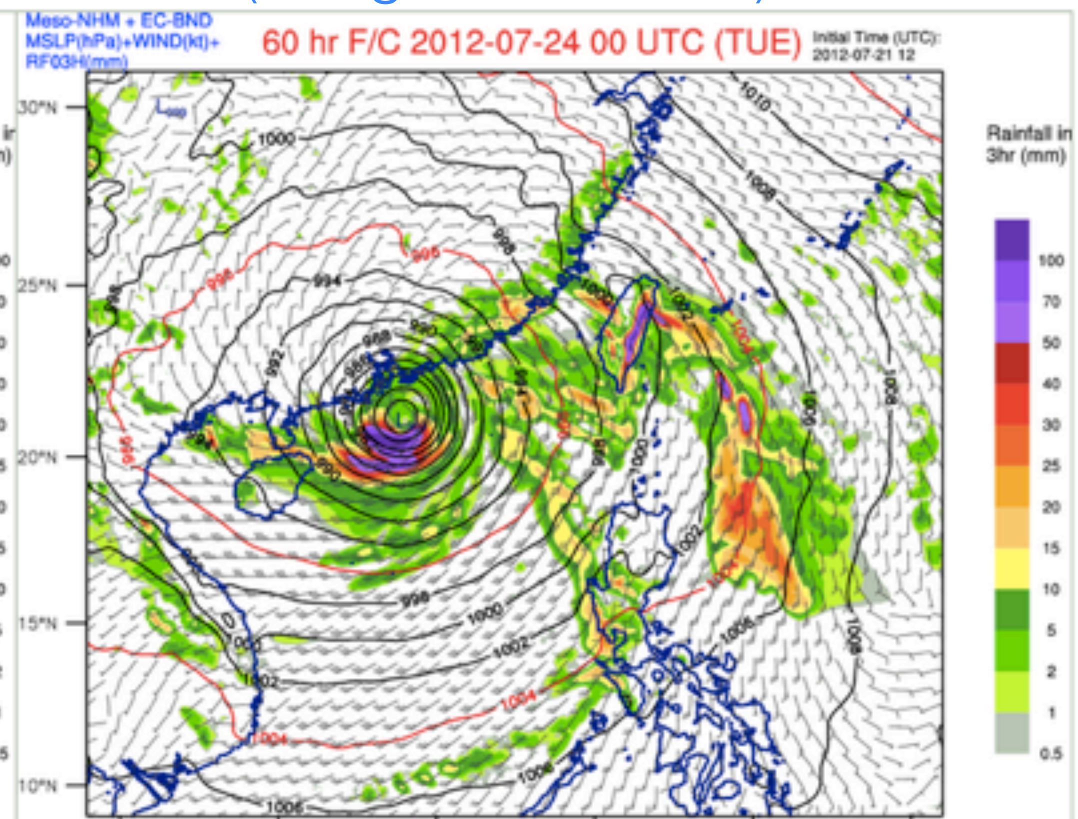
Quantitative Precipitation Forecasts (QPF)

Multi-model scenario (global vs. regional)

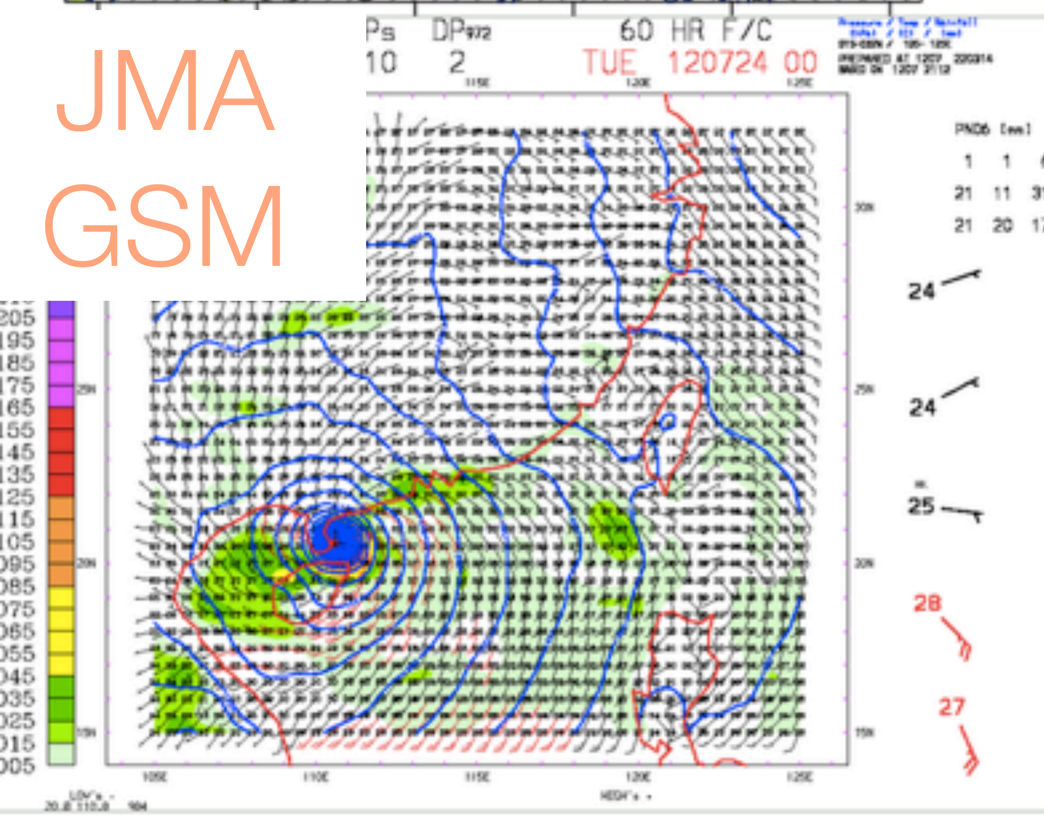
Meso-NHM (operational version)



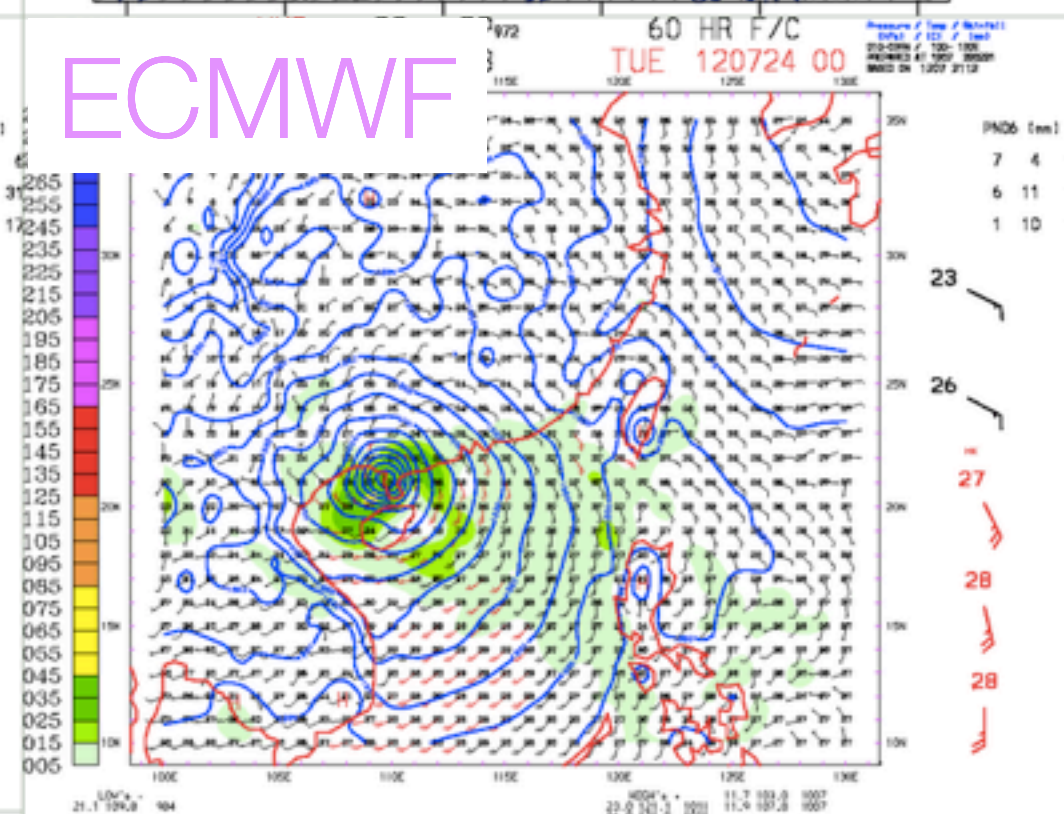
Meso-NHM (using ECMWF BC)



JMA GSM

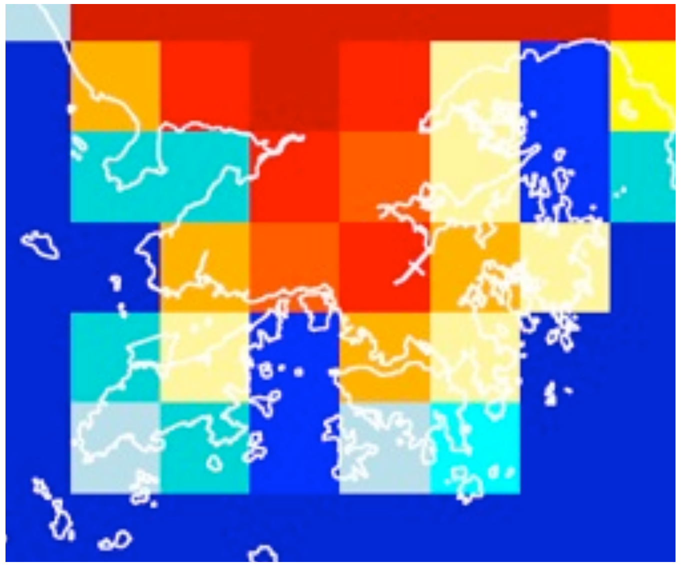


ECMWF

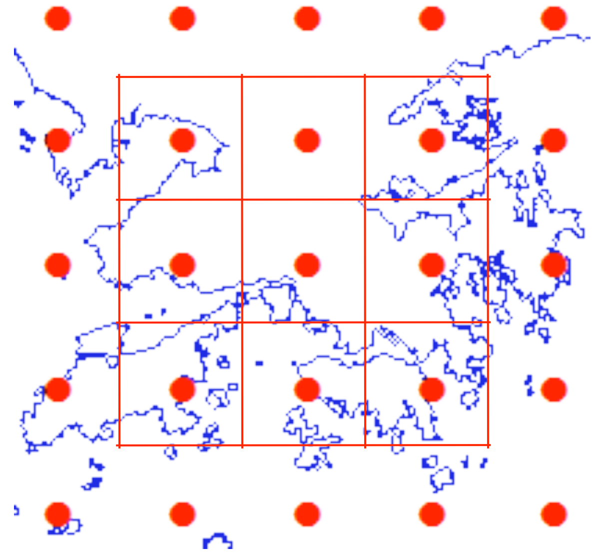


Assessment of model QPF performance over HK

Meso-NHM - all land boxes (~ 10 km)

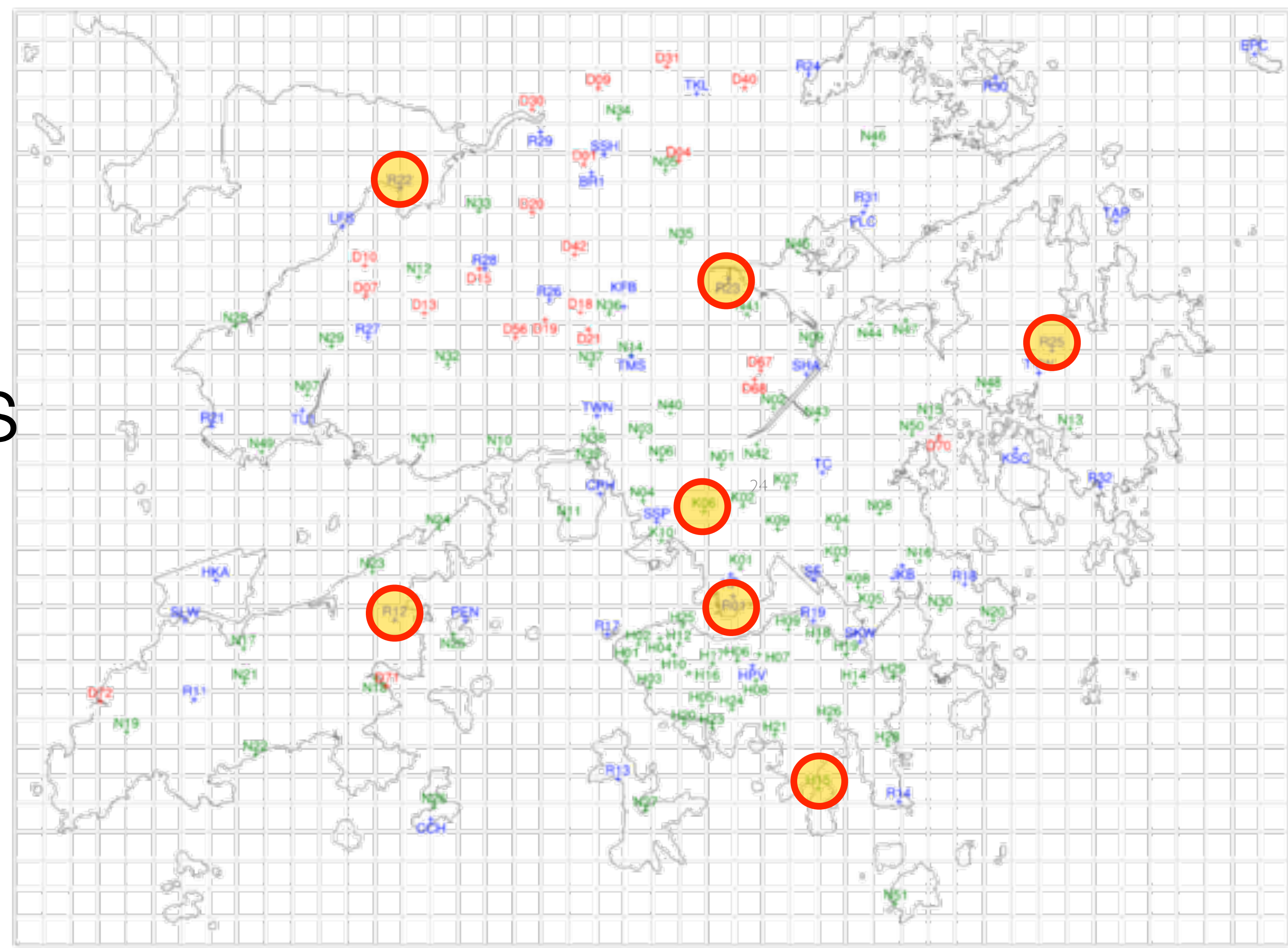


ECMWF – center 9 boxes (0.125 deg)



JMA – center 4 boxes (0.25 deg)

Verifying raingauges

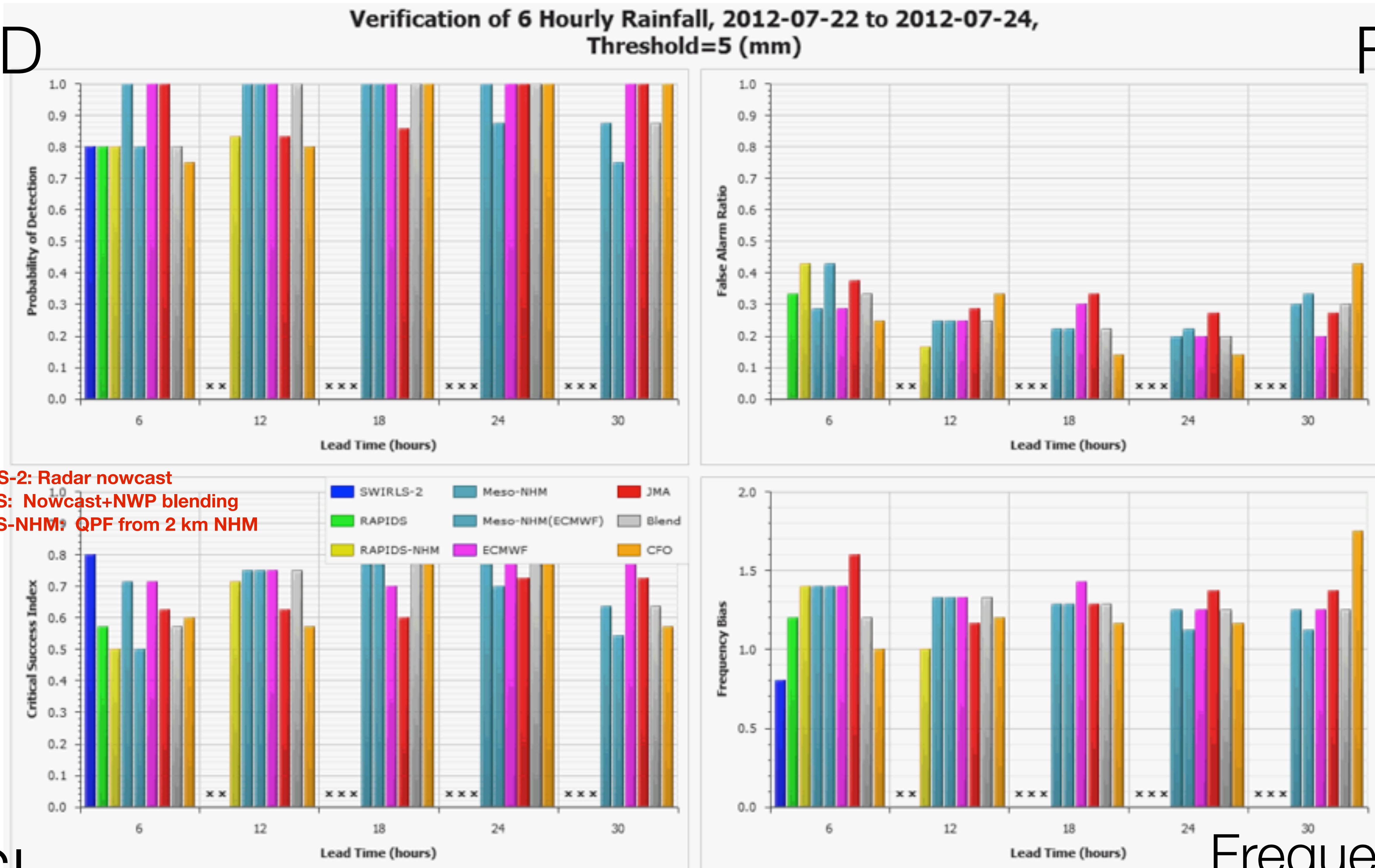


* straight lines represent analysis grid with spacing : ~1.4 km (N-S) ; ~1.5 km (E-W)

- Verification of 6 Hourly Rainfall
  - 22 - 24 July 2012

POD

FAR



Note:
SWIRLS-2: Radar nowcast
RAPIDS: Nowcast+NWP blending
RAPIDS-NHM: QPF from 2 km NHM

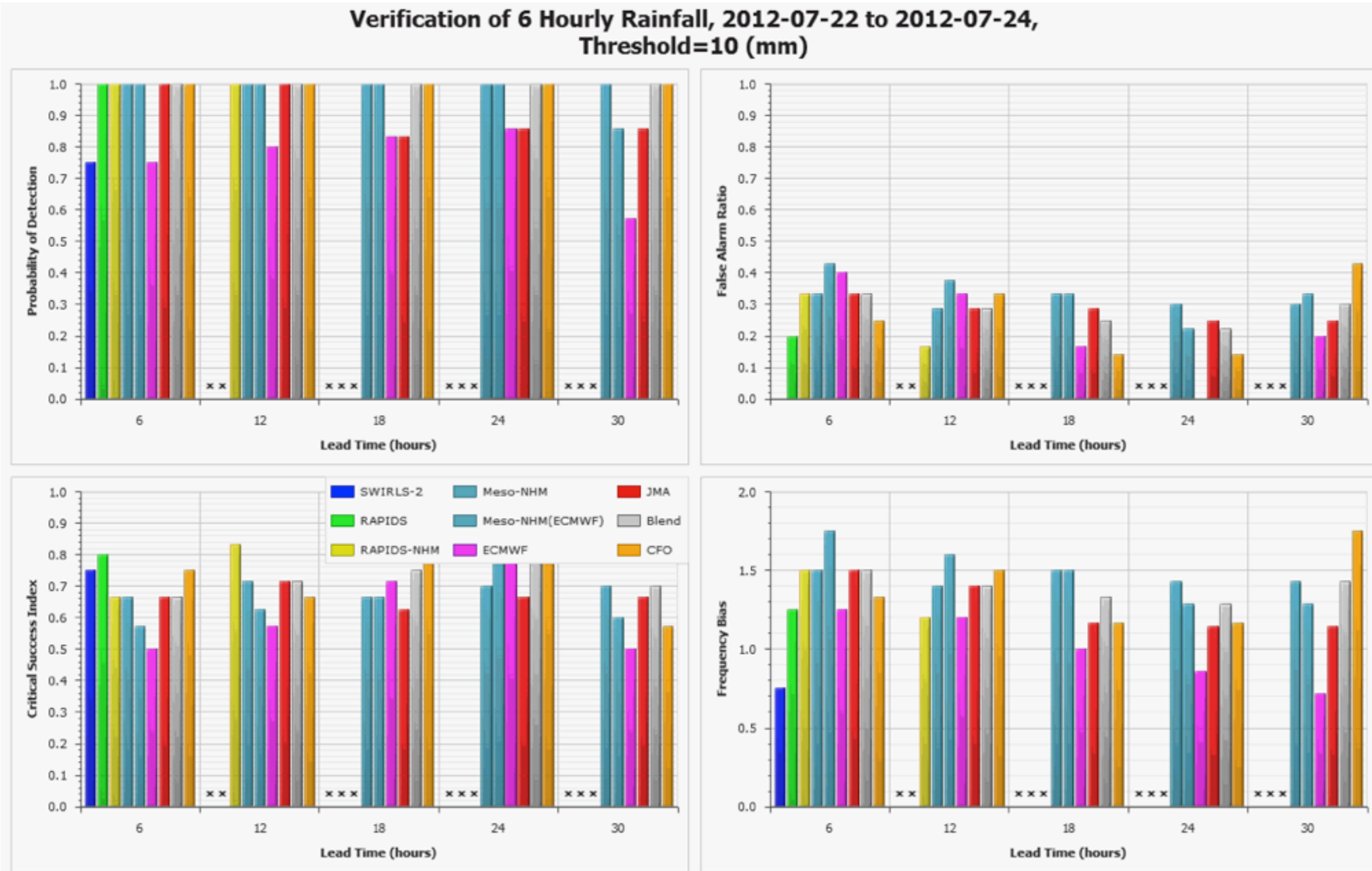
CSI

Frequency Bias

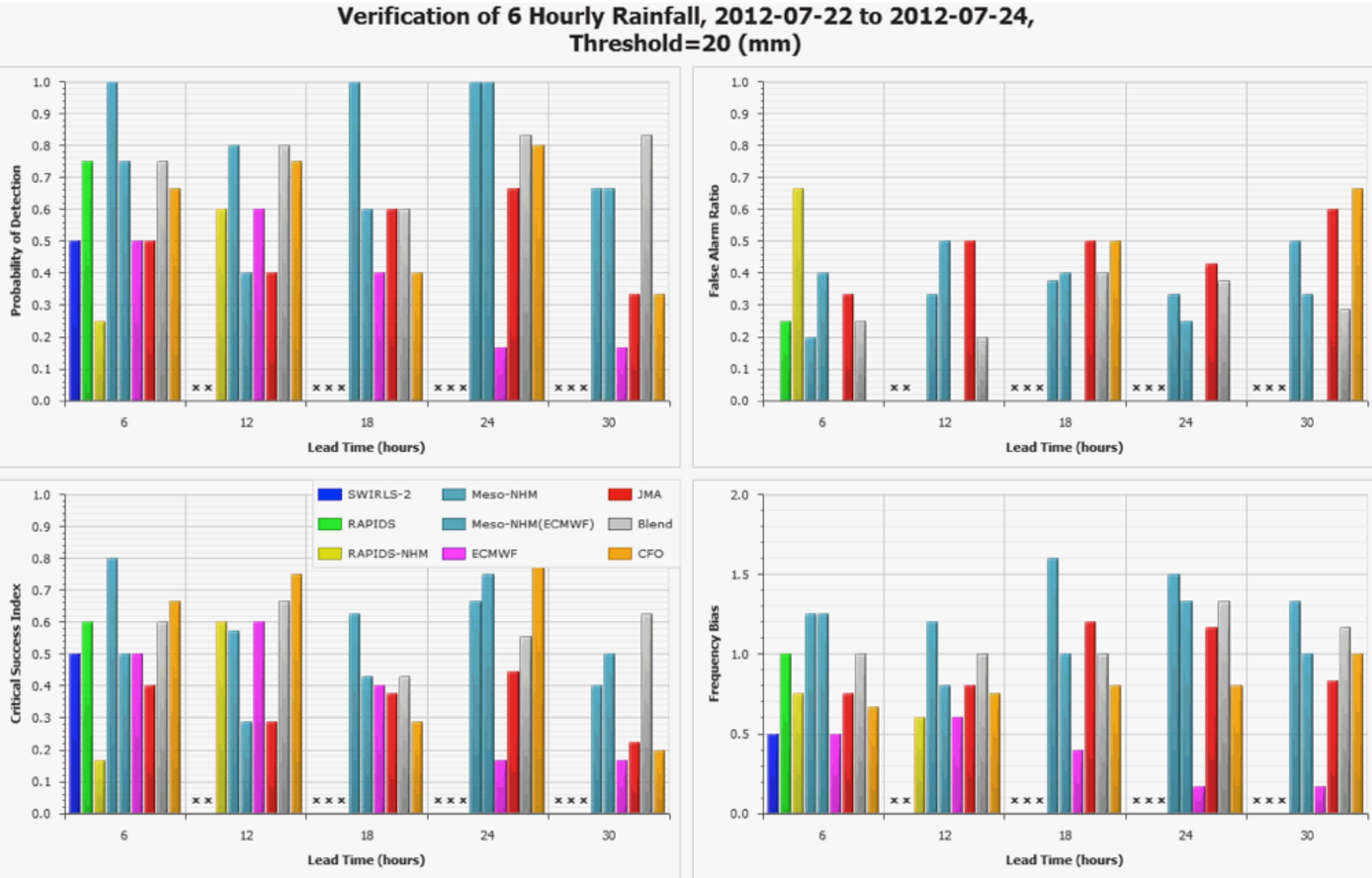
- Verification Scores:

  - POD = Probability of Detection = no. of hit / (no. of hit + no. of miss)
  - FAR = False Alarm Ratio = no. of false / (no. of false + no. of hit)
  - CSI = Critical Success Index (Threat Score) = no. of hit / (no. of hit+miss+false)
  - Frequency Bias = (no. of hit + false) / (no. of hit + miss)
    - bias > 1 (over-forecast)
    - bias < 1 (under-forecast)

- Threshold = 10 mm (in 6 hours)

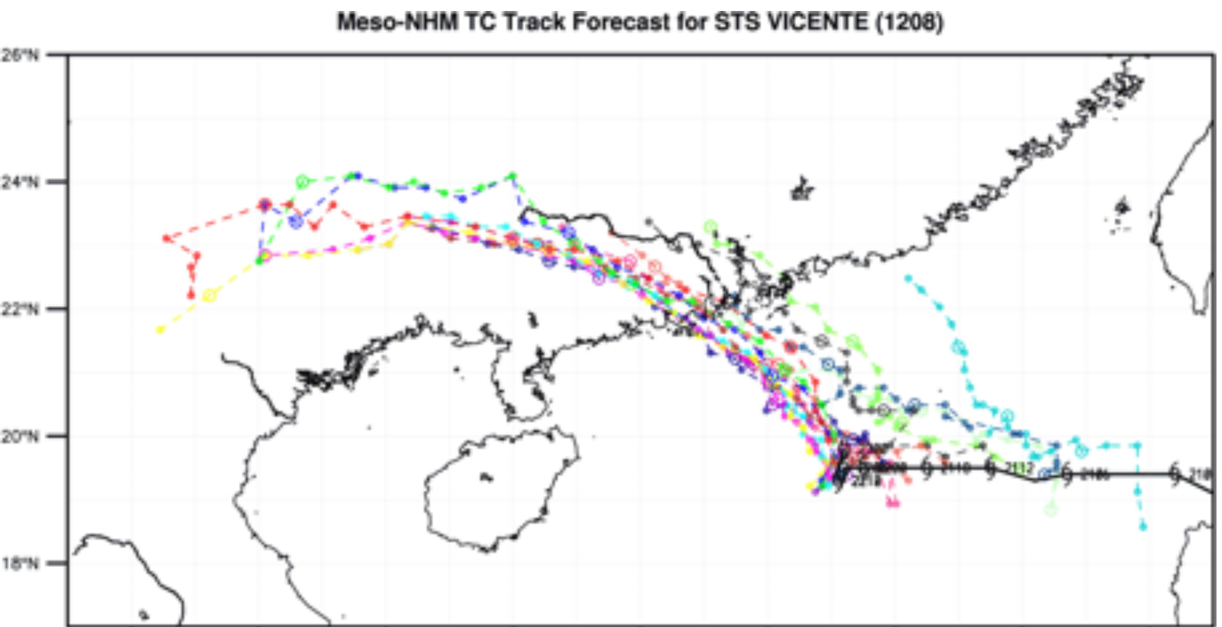


• Threshold = 20 mm (in 6 hours)

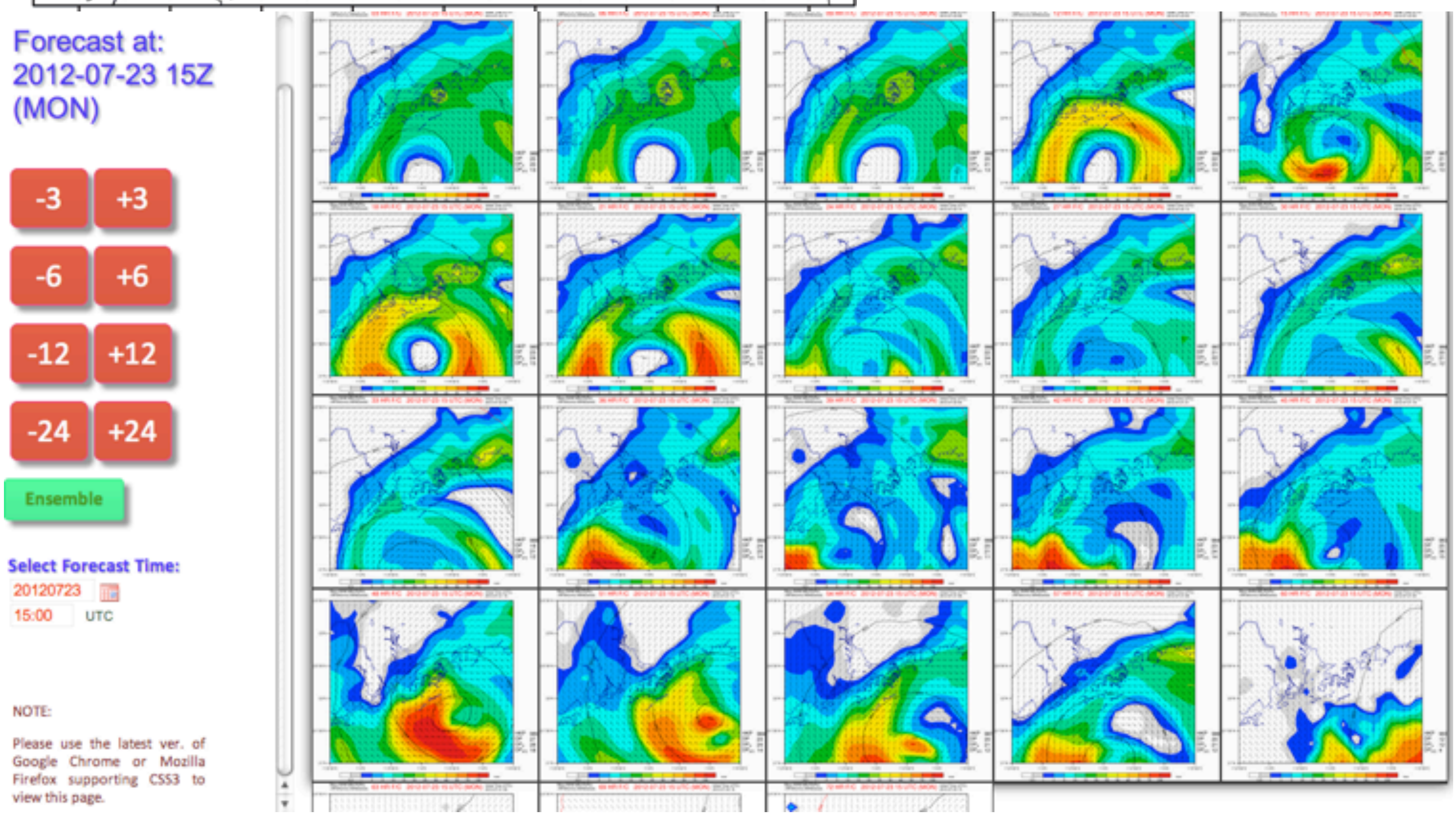


Optimizing usage of rapid-update QPF from NHM

- Rapid-update cycle

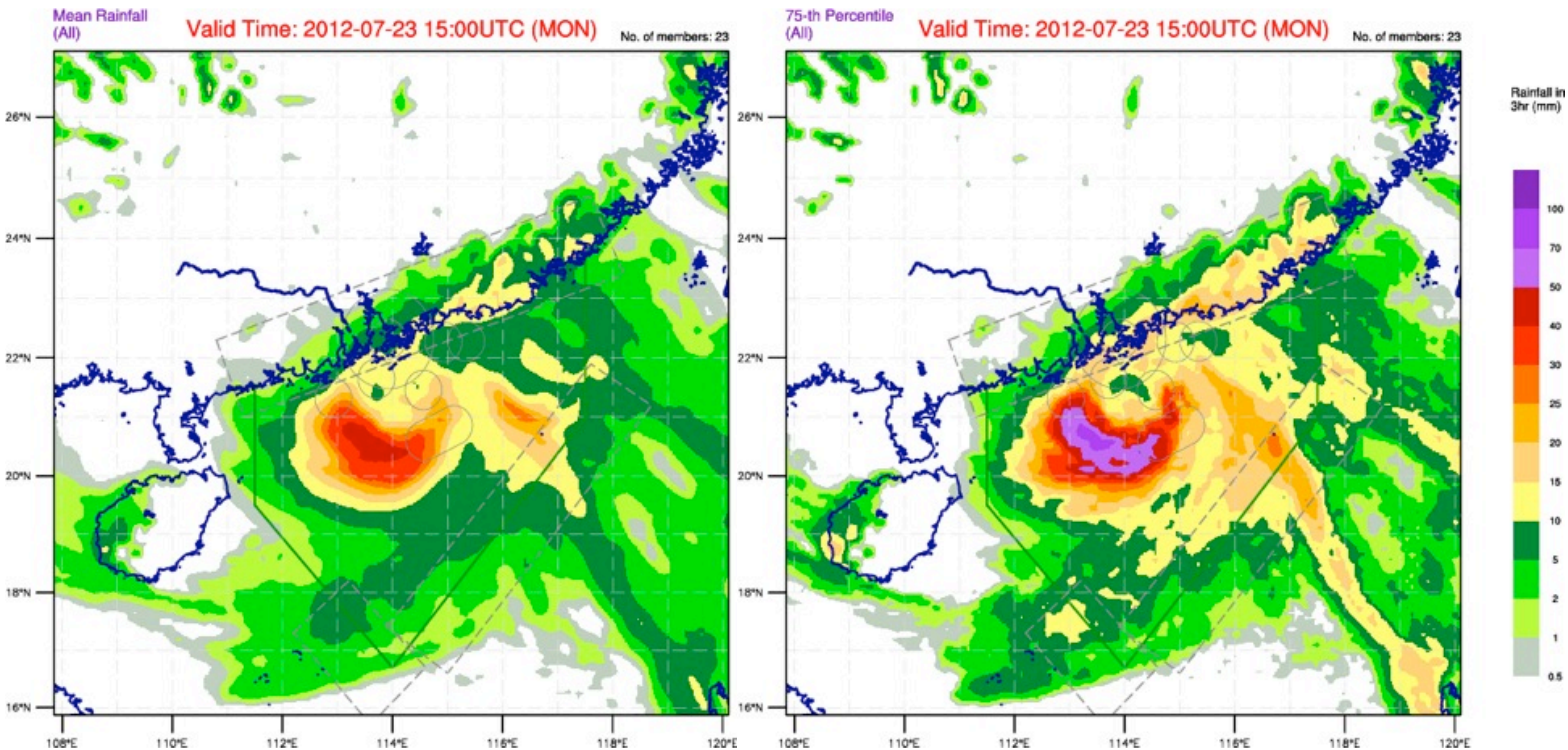


Forecast TC tracks and model QPF "stamp map" from successive 3-hourly update Meso-NHM runs



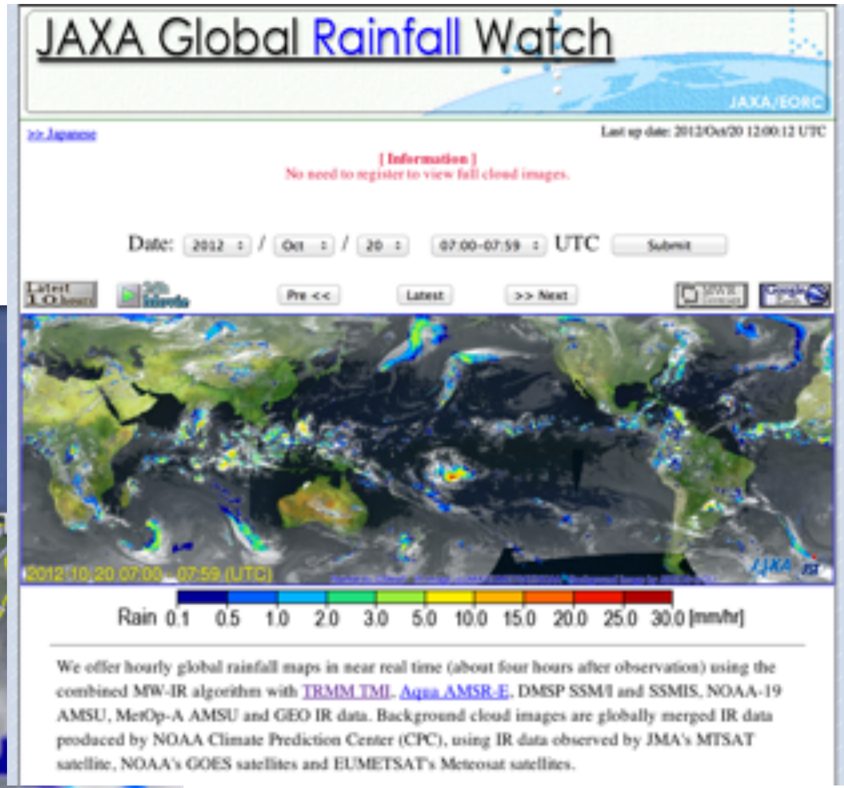
QPF from ALL available Meso-NHM runs forecast at 15 UTC 23 July 2012

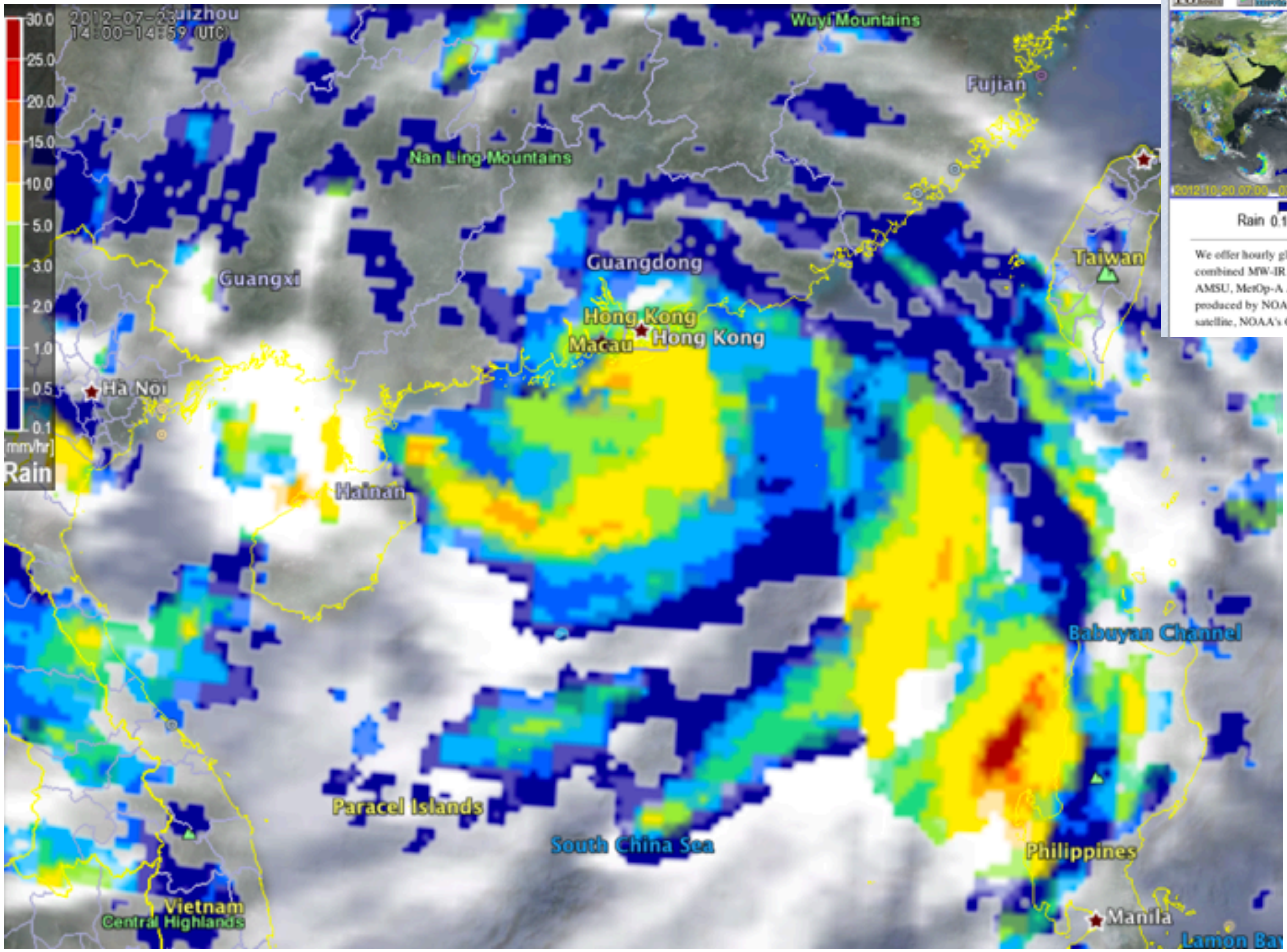
- time-lagged ensemble QPF
  - mean and 75-th percentile gridded QPF

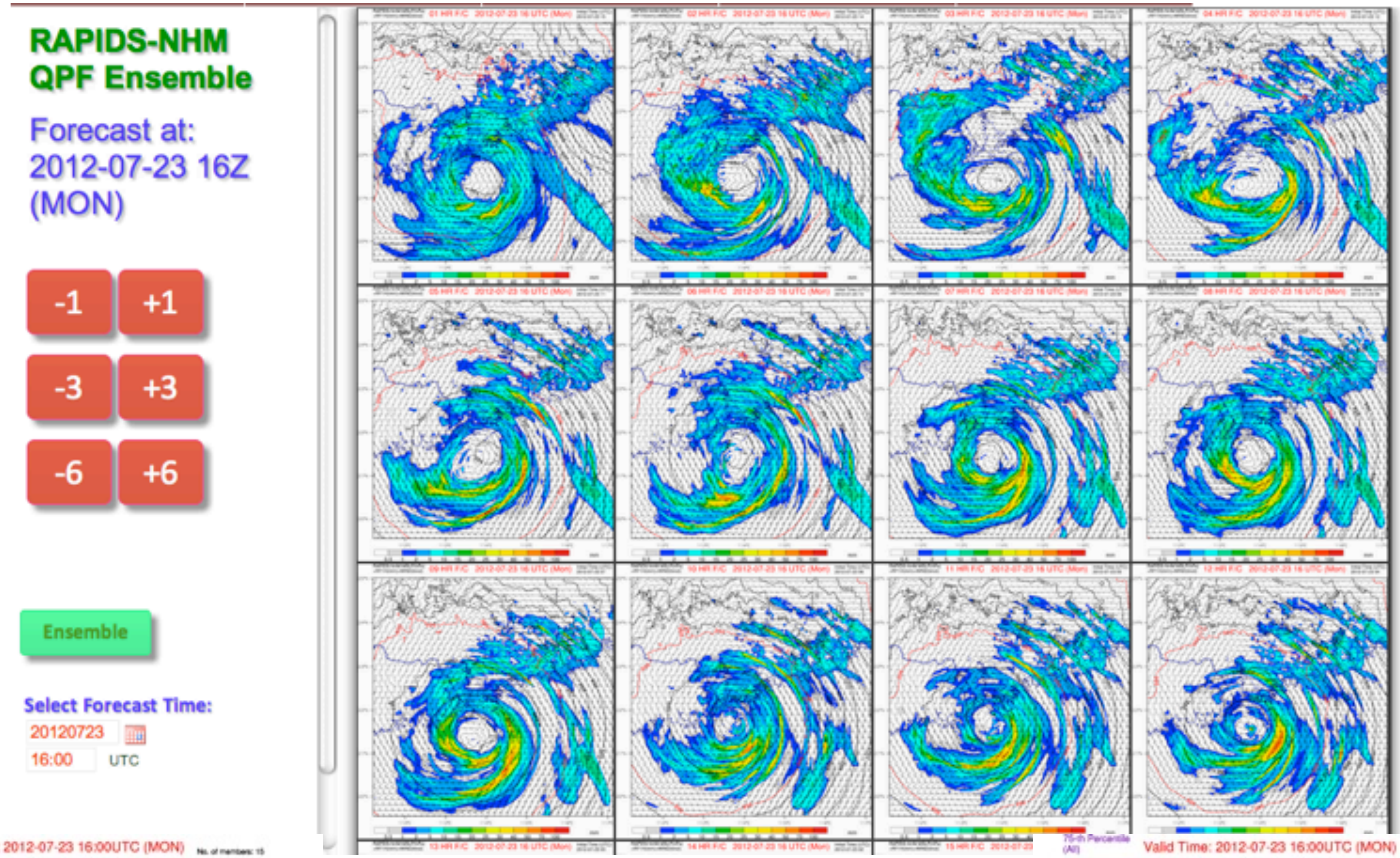


- Comparison with satellite rainfall estimate

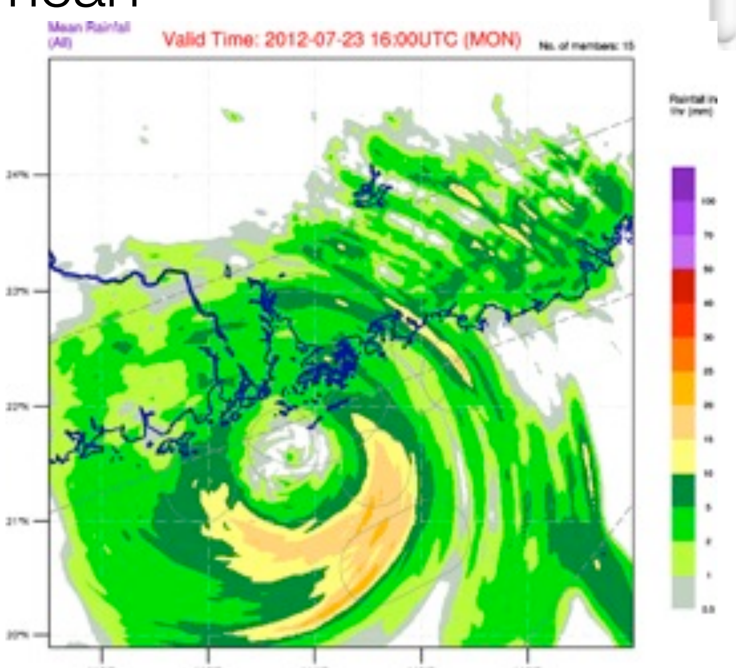
JAXA global rainfall estimate using microwave-IR combined algorithm
http://sharaku.eorc.jaxa.jp/GSMaP/

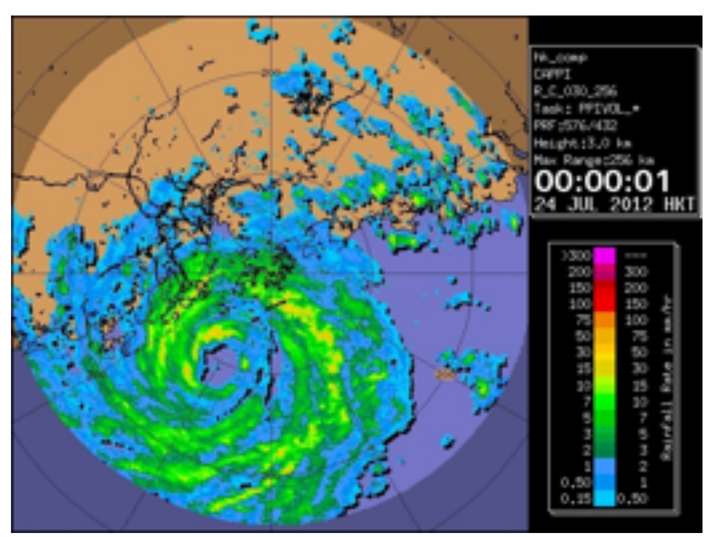




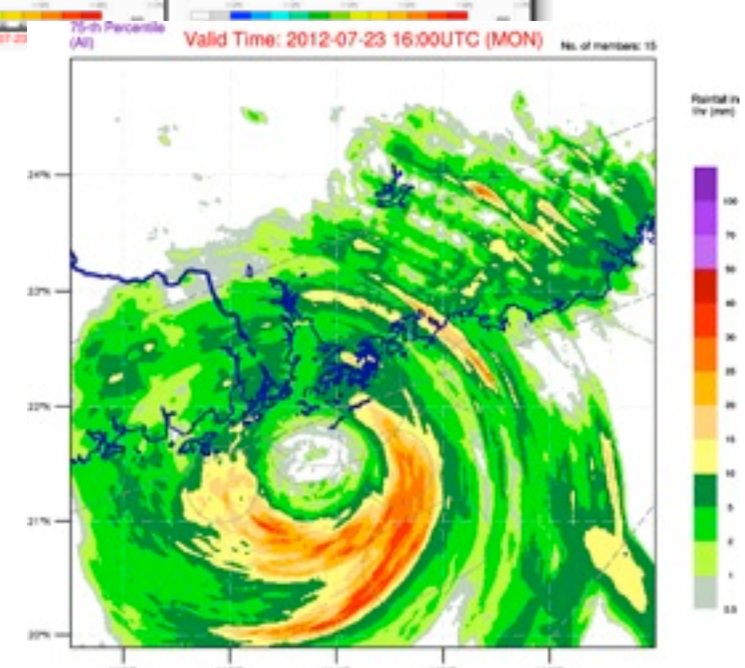


Ensemble mean





75-th percentile



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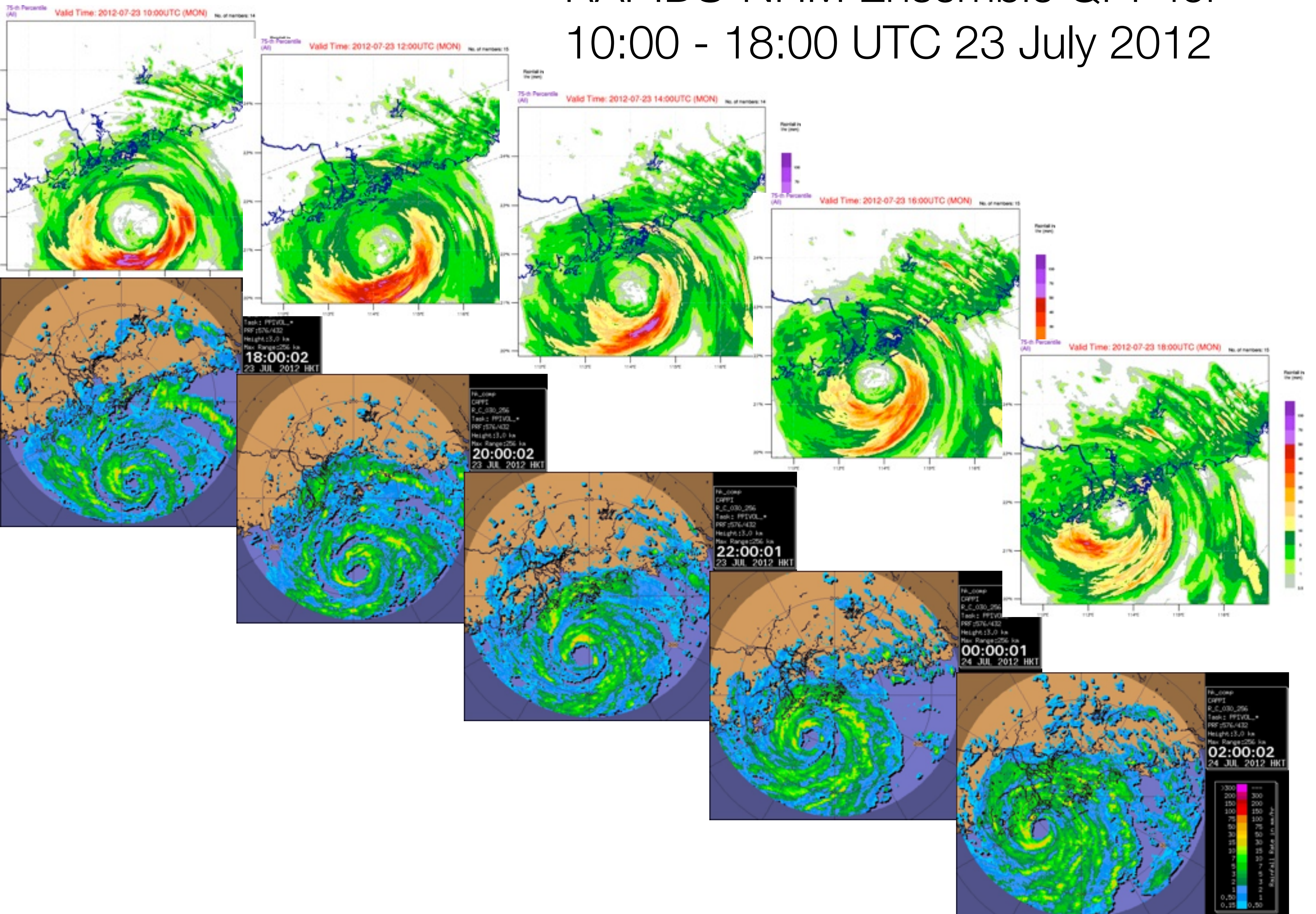
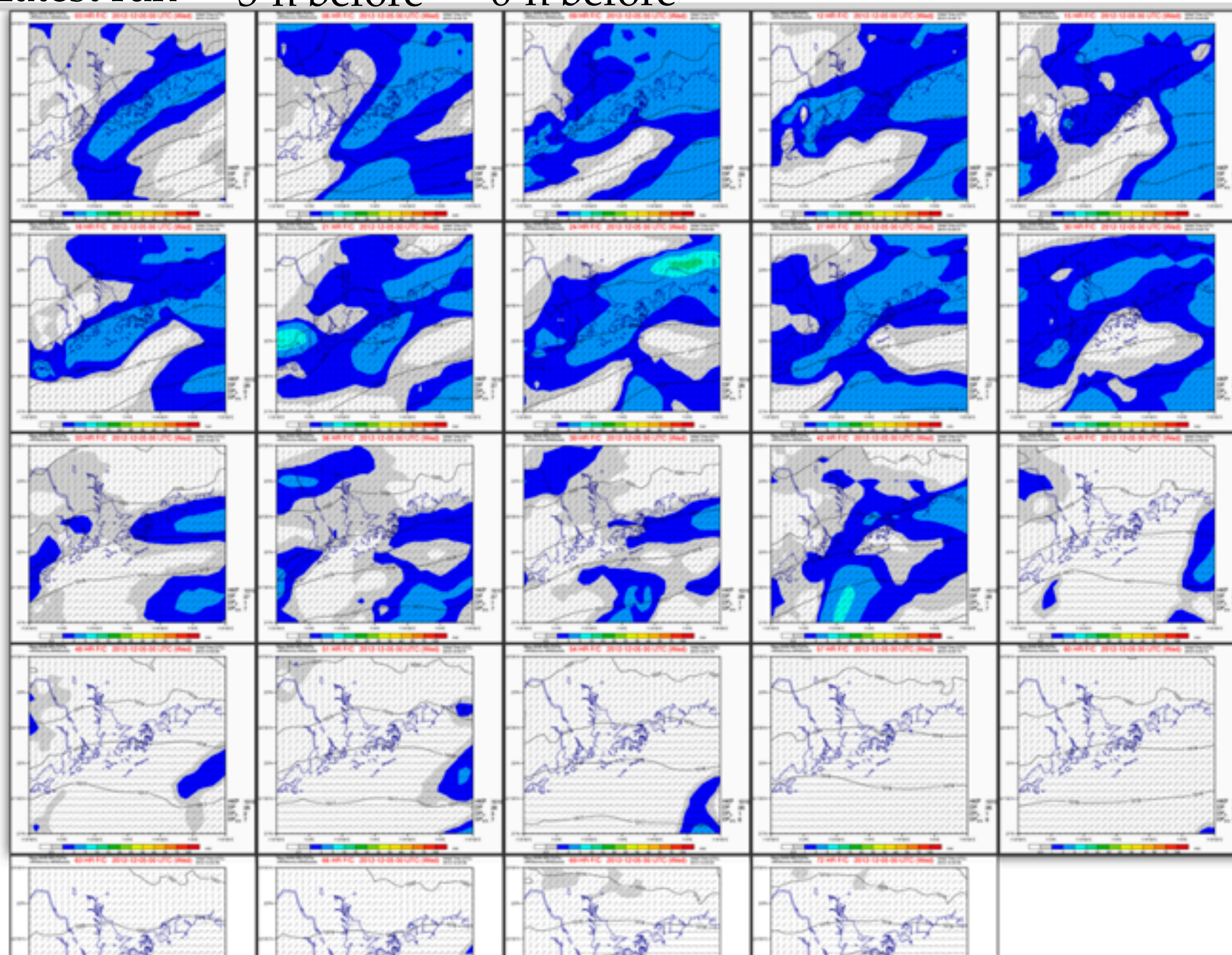
RAPIDS-NHM Ensemble QPF for 10:00 - 18:00 UTC 23 July 2012



Meso-NHM QPF-Ensemble in operation

Stamp maps showing <u>ALL available</u> Meso-NHM forecasts valid at 2012-12-05 00Z

Latest run 3-h before 6-h before



Meso-NHM QPF Ensemble

Forecast at:
2012-12-05 00Z
(WED)

Time control

-3 +3

-6 +6

-12 +12

-24 +24

View ensemble QPF

Ensemble

Calendar

Select Forecast Time:
20121205
06:00 UTC

NOTE:

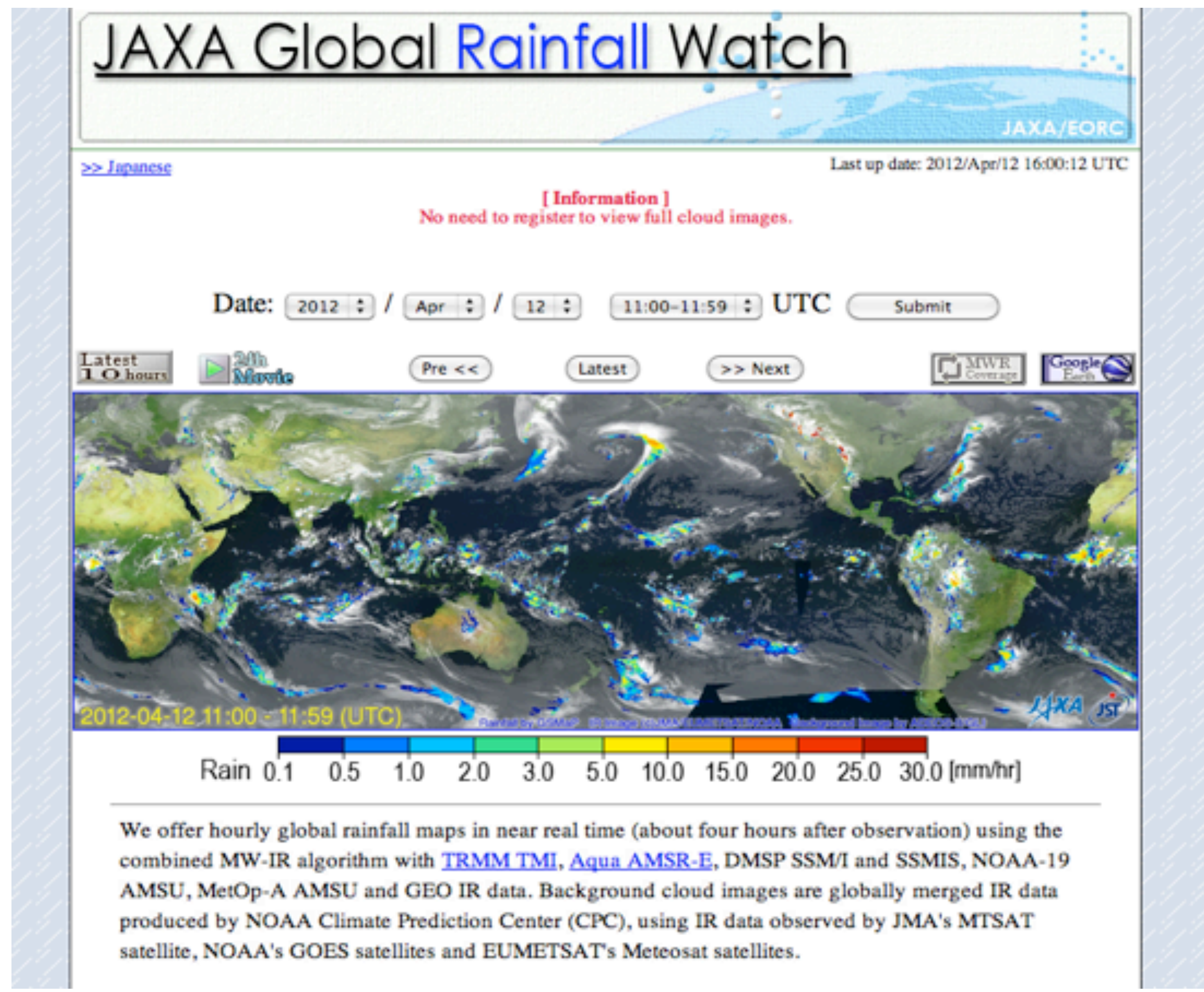
Please use the latest ver. of Google Chrome or Mozilla Firefox supporting CSS3 to view this page.

Performance of “ensemble QPF”

- Any benefit from this time-lagged ensemble QPF compared to individual “member” model run ?

Verifying QPE

- JAXA Global Rainfall Watch Data
  - Near-real-time hourly rainfall rate based on MW-IR algorithm with TRMM TMI, Aqua AMSR-E, DMSP SSM/I and SSMIS, NOAA-19 AMSU, MetOp-A AMSU and GEO IR data
  - 0.1 degree resolution
    - similar to Meso-NHM

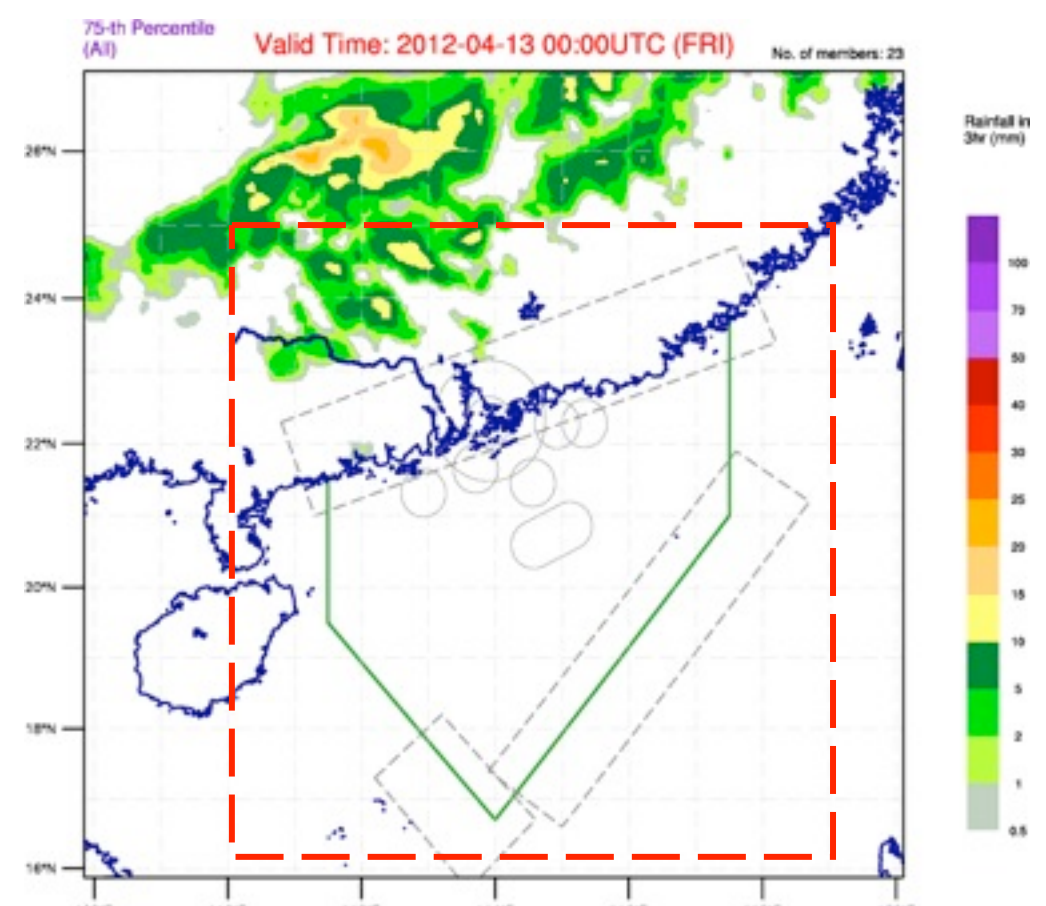


Verification

- Period: 2 July 2011 – 30 September 2011
- Meso-NHM QPF products:
  - Meso-NHM 3-hour accumulated rainfall (00,03,06,09,…, 21 UTC model runs); T+3, T+6, ..., T+72 h
  - Ensemble QPF (mean and 75-th percentile, “All” and “Rainy Grids”)
- Grid-based (0.1x0.1 deg. lat/lon grid) verification

  threshold >= 5mm/3 hour

- Verification Domain:
  - 16.05 N – 24.95 N



香港天文台 Hong Kong Observatory

Results from individual model runs from T+0 to T+72h

Threshold: 5 mm / 3 hrs

Forecast Hours (FT)

FT/hr	6	12	18	24	30	36	42	48	54	60	66	72
POD	**0.18**	**0.22**	**0.21**	**0.21**	**0.20**	**0.19**	**0.19**	**0.18**	**0.17**	**0.17**	**0.17**	**0.15**
FAR	**0.65**	**0.69**	**0.74**	**0.75**	**0.77**	**0.79**	**0.80**	**0.81**	**0.83**	**0.84**	**0.84**	**0.87**
CSI	**0.13**	**0.15**	**0.13**	**0.13**	**0.12**	**0.11**	**0.11**	**0.10**	**0.09**	**0.09**	**0.09**	**0.08**
PSS	**0.16**	**0.19**	**0.18**	**0.18**	**0.17**	**0.16**	**0.15**	**0.14**	**0.12**	**0.12**	**0.12**	**0.10**

POD = H/(H+M);

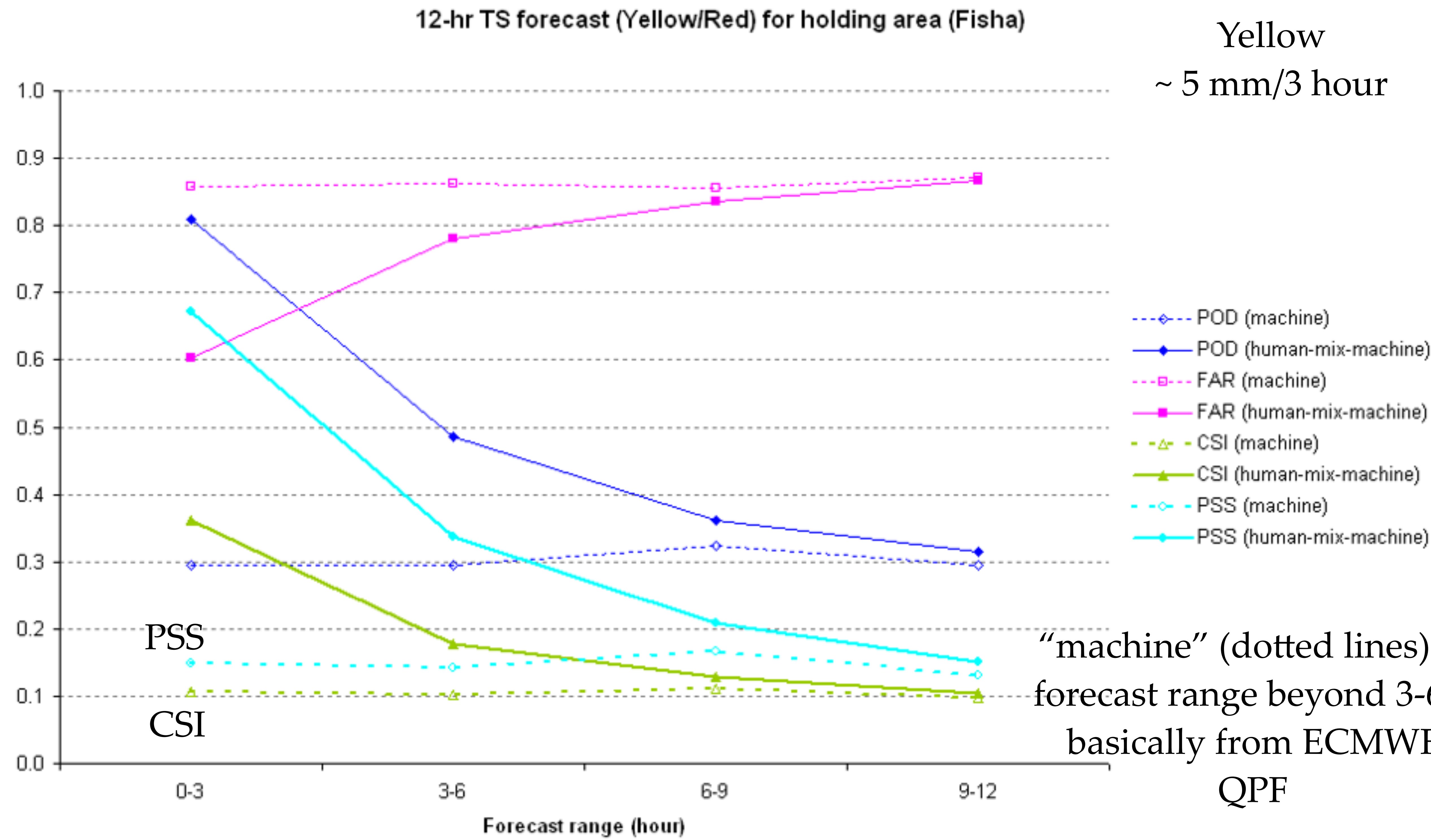
FAR = F/(H+F);

CSI = H/(H+M+F);

PSS (Pierce's Skill Score) = H/(H+M) – F/(F+Z)

H = hit; M = miss; F = false alarm; Z = correct negative

Area based verification using ECMWF QPF



Yellow
~ 5 mm/3 hour

"machine" (dotted lines) at forecast range beyond 3-6 h basically from ECMWF QPF

Verification results of sig. convection forecasts for holding area "Fisha"
2011-08-22 to 2011-10-16

Verification of Ensemble QPF

	75-th percentile	75-th percentile (rainy grid)	mean	mean (rainy grid)
POD	**0.296**	**0.287**	**0.19**	**0.18**
FAR	**0.737**	**0.735**	**0.67**	**0.67**
CSI	**0.162**	**0.160**	**0.13**	**0.13**
PSS	**0.254**	**0.247**	**0.17**	**0.16**

Compare with individual Meso-NHM forecasts:

FT/hr	6	12	18	24	30	36	42	48	54	60	66	72
POD	**0.18**	**0.22**	**0.21**	**0.21**	**0.20**	**0.19**	**0.19**	**0.18**	**0.17**	**0.17**	**0.17**	**0.15**
FAR	**0.65**	**0.69**	**0.74**	**0.75**	**0.77**	**0.79**	**0.80**	**0.81**	**0.83**	**0.84**	**0.84**	**0.87**
CSI	**0.13**	**0.15**	**0.13**	**0.13**	**0.12**	**0.11**	**0.11**	**0.10**	**0.09**	**0.09**	**0.09**	**0.08**
PSS	**0.16**	**0.19**	**0.18**	**0.18**	**0.17**	**0.16**	**0.15**	**0.14**	**0.12**	**0.12**	**0.12**	**0.10**

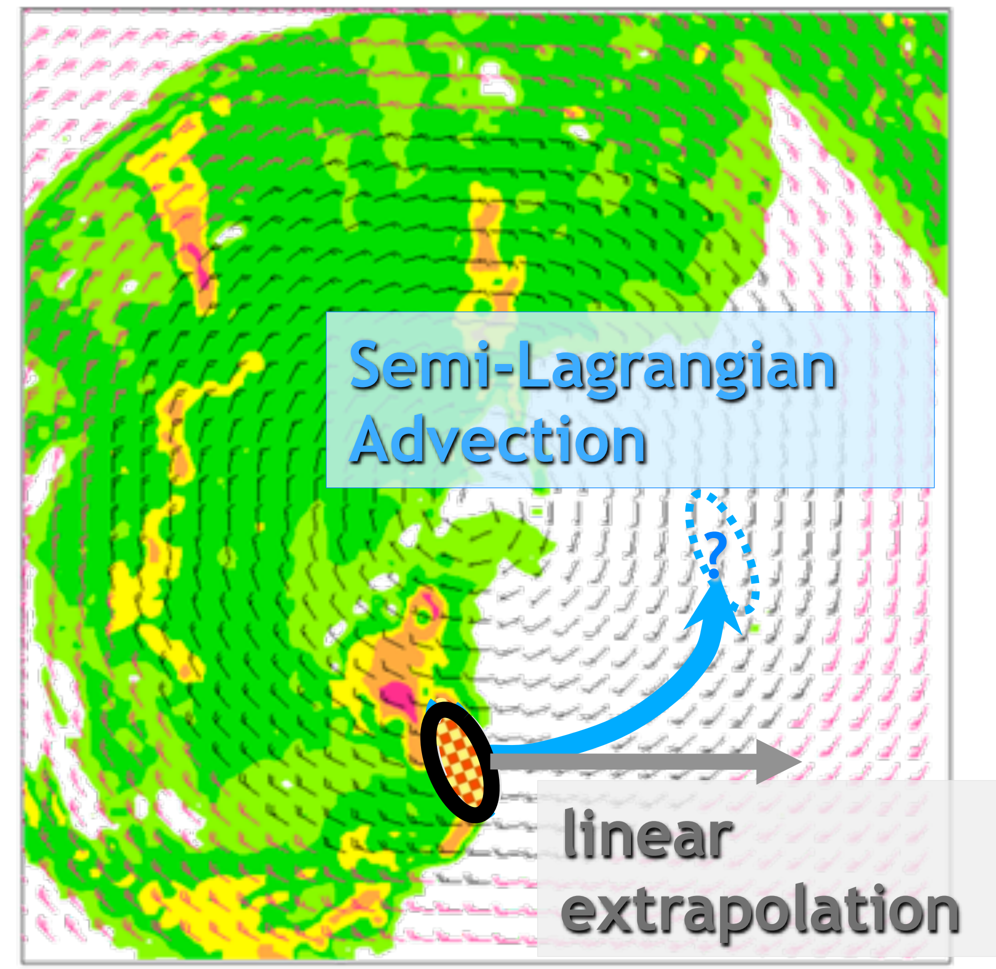
Model QPF

- multi-model approach and rapid-update cycle mesoscale NWP QPF:
    - alternative scenarios of significant rain
    - objective guidance to help and provide (useful) ‘first-guess’ to forecasters on the analysis and diagnosis of synoptic situation and mesoscale process
- Another use of model QPF to improve short-term (or nowcast) of precipitation:
    - blending with radar nowcasting (extrapolation of radar echoes)

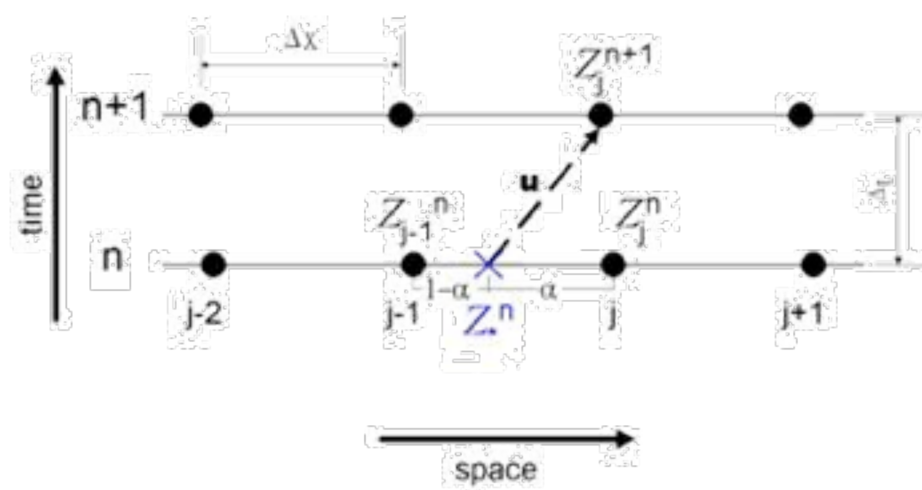
Radar Nowcast by Extrapolation

- Semi-Lagrangian Advection

$$\frac{dZ}{dt} = \frac{\partial Z}{\partial t} + \mathbf{u}\frac{\partial Z}{\partial x} = 0$$



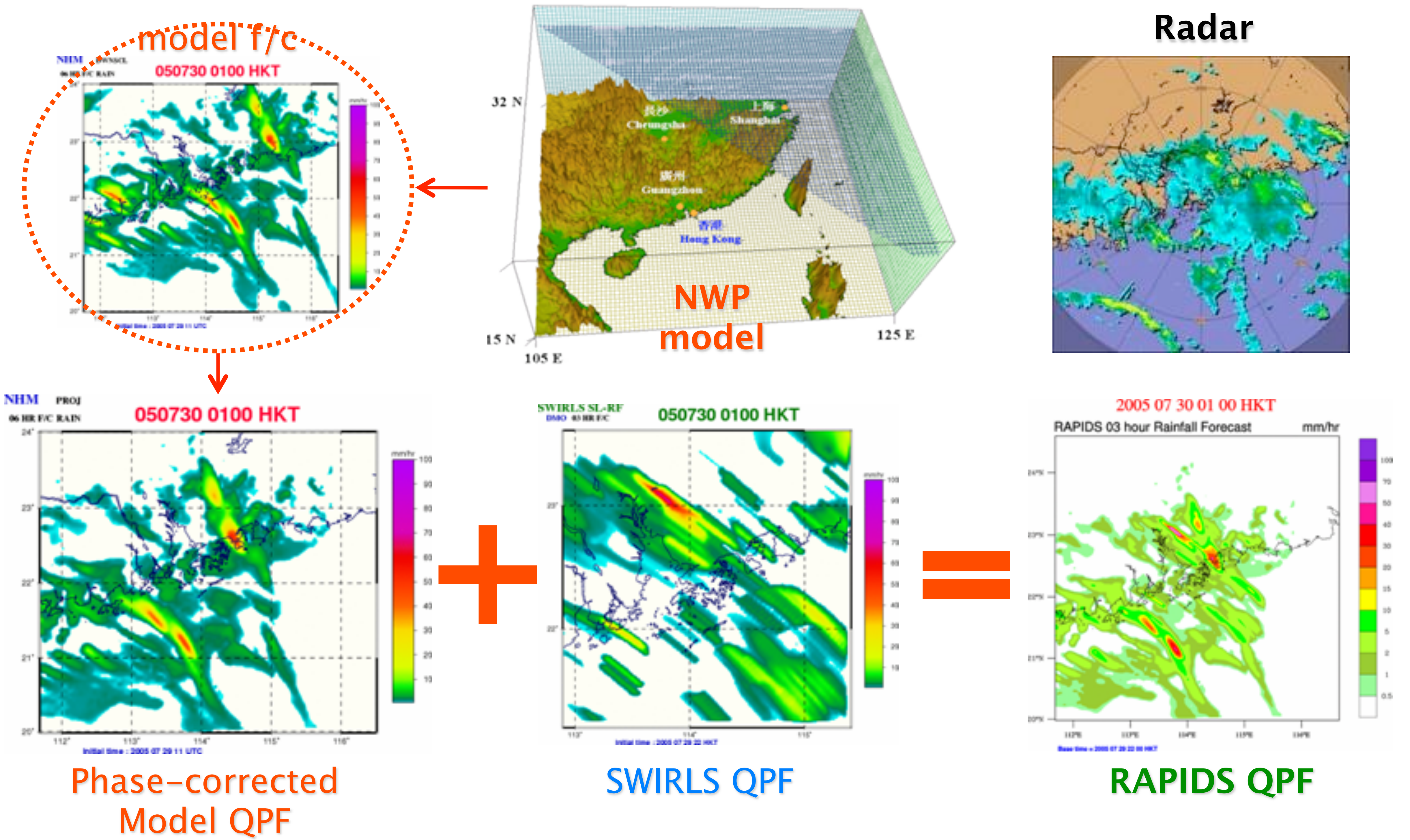
  - 3 iteration to locate departure point
  - bi-cubic interpolation to determine reflectivity at departure point



  - flux limiter based on local max/min constraint
  - horizontal resolution at 1.1 km - 0.5 km with one-way nesting (256 km to 128 km range of CAPPI reflectivity)

Blending of QPFs

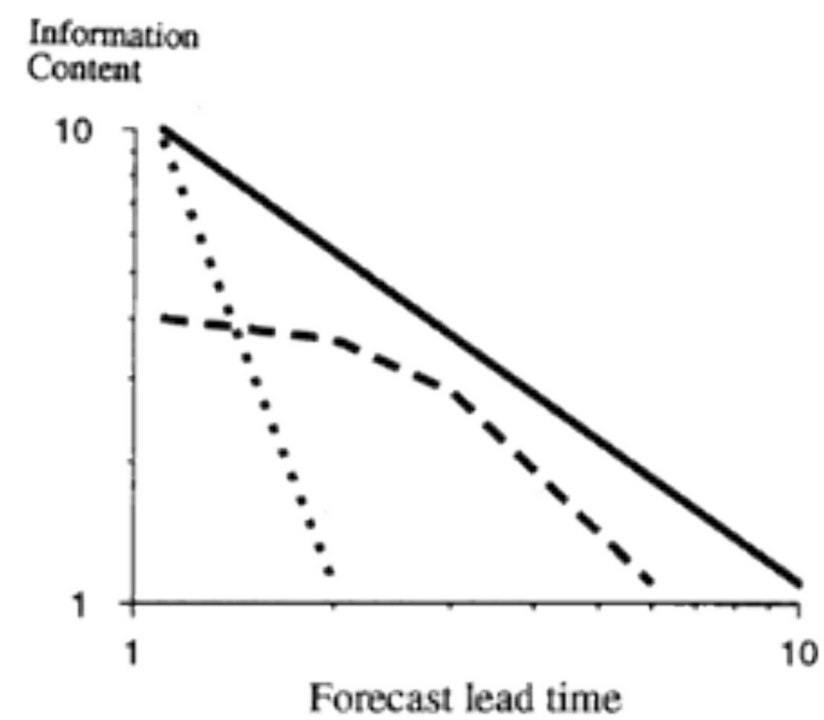
Merging Nowcast with NWP

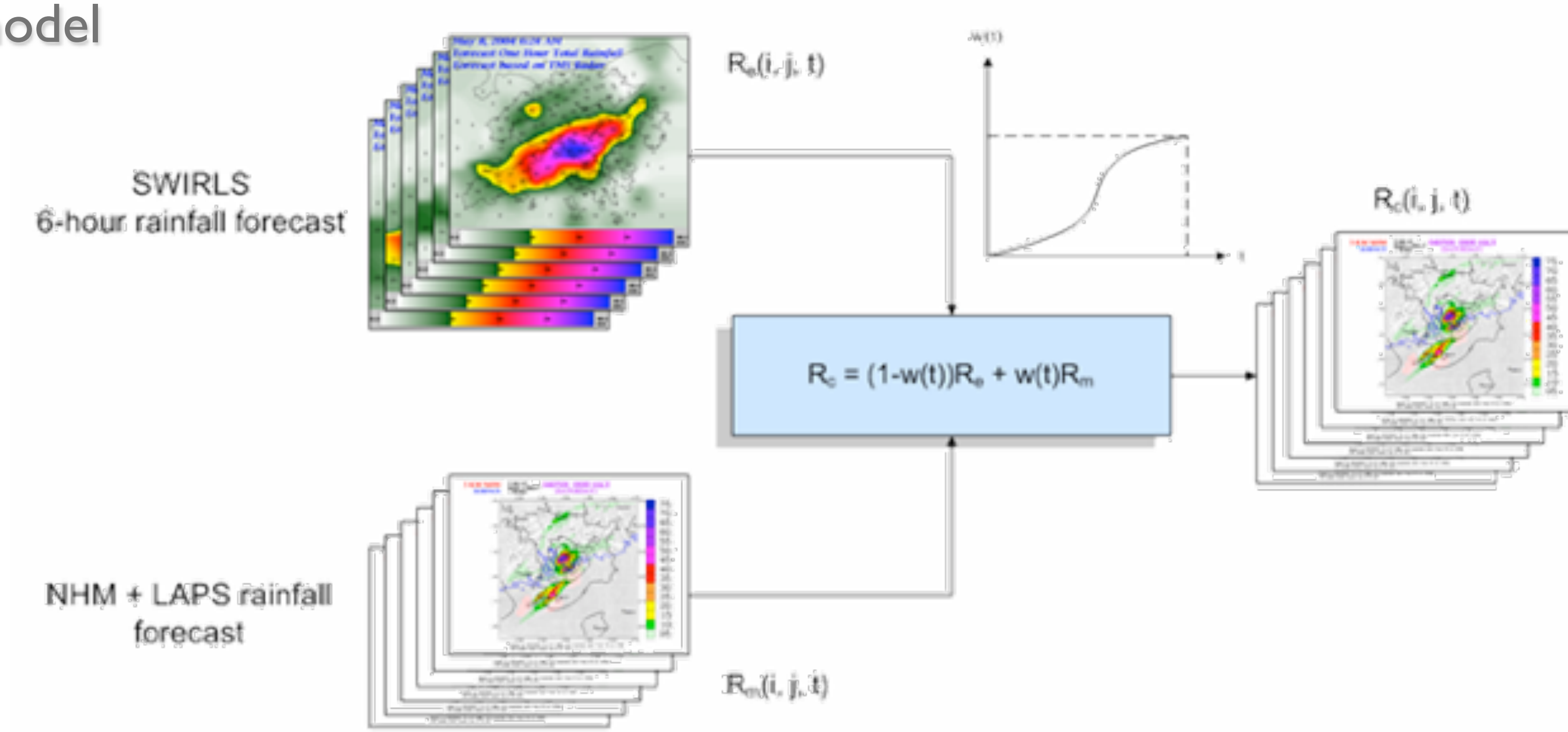


RAPIDS

(Rainstorm Analysis and Prediction Integrated Data-processing System)

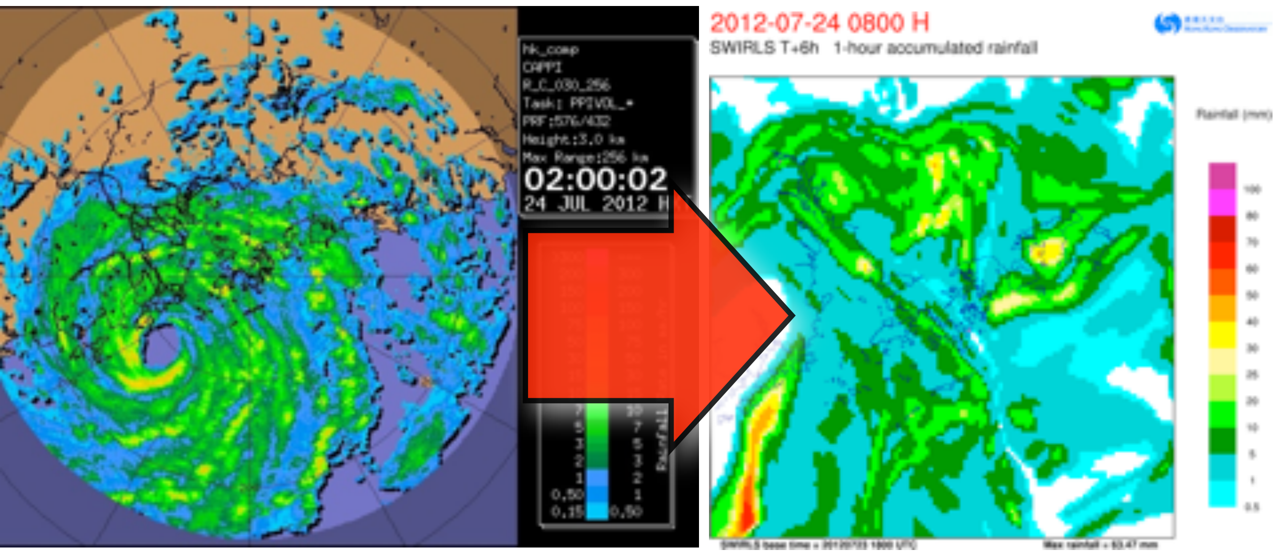
- to provide 1-6 hours blended QPF
- 2-km resolution, hourly/6-min updating
- NOWCASTING component – SWIRLS
  - QPF by semi-Lagrangian advection of radar echoes
- NWP component – NHM
  - QPF by non-hydrostatic model





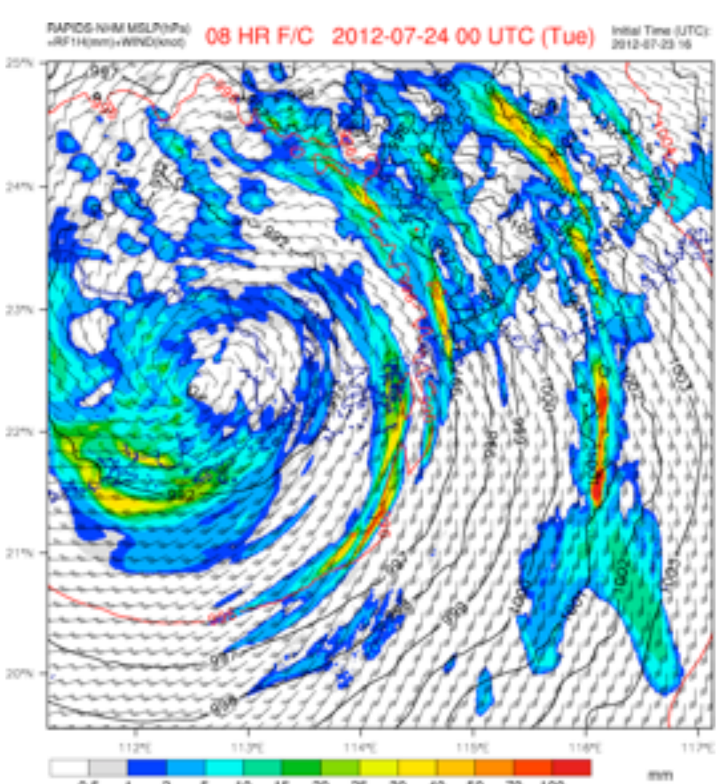
RAPIDS : QPF Blending

ST Vicente (2012-07-24 02:00 HKT)



SWIRLS-2 radar nowcast (1-6 hr)
(optical flow tracking, semi-Lagrangian advection)

RAPIDS-NHM forecast



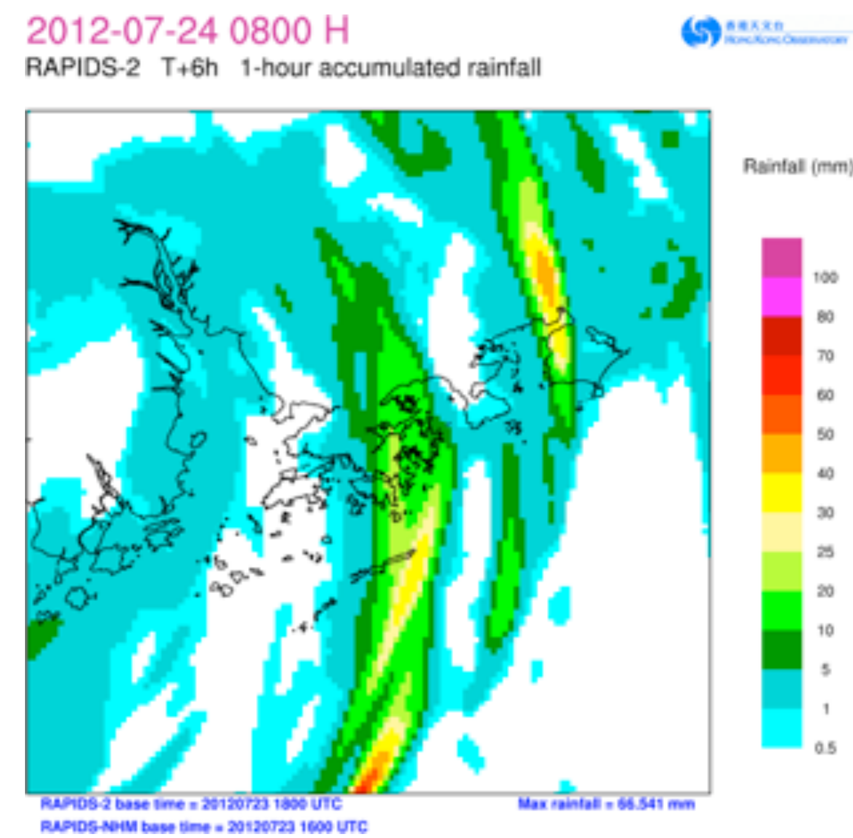
Blending

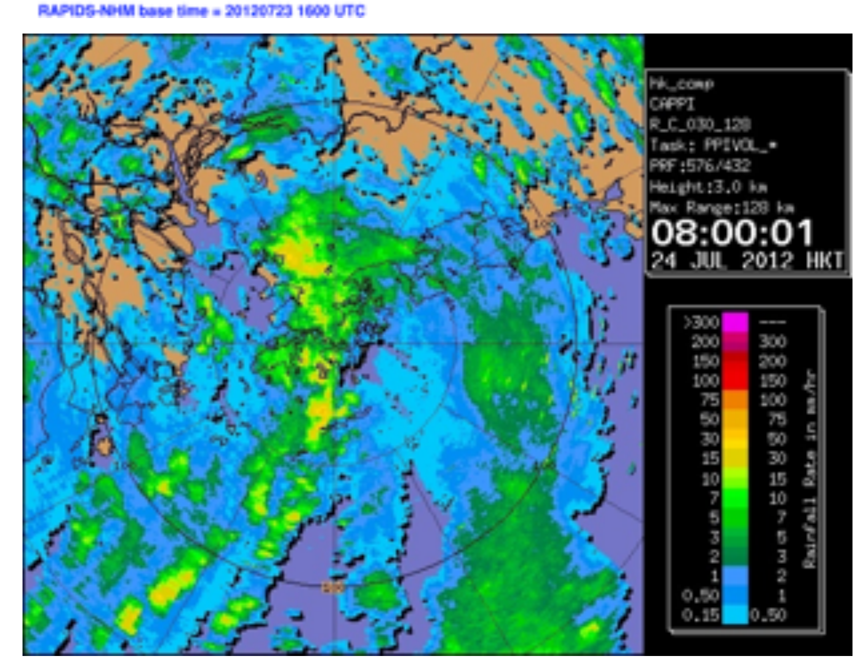
Phase correction of position error

Intensity calibration to adjust model rainfall intensity

Superposition on radar nowcast using time-dependent weighting

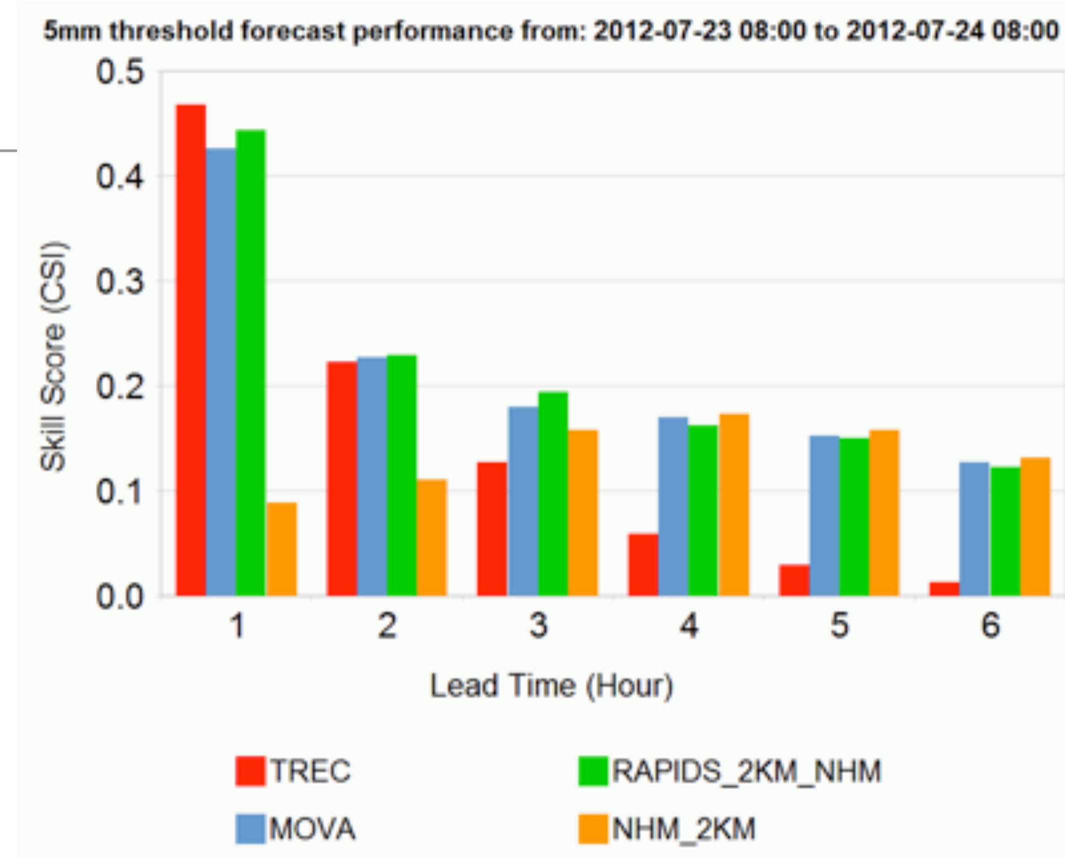
RAPIDS QPF



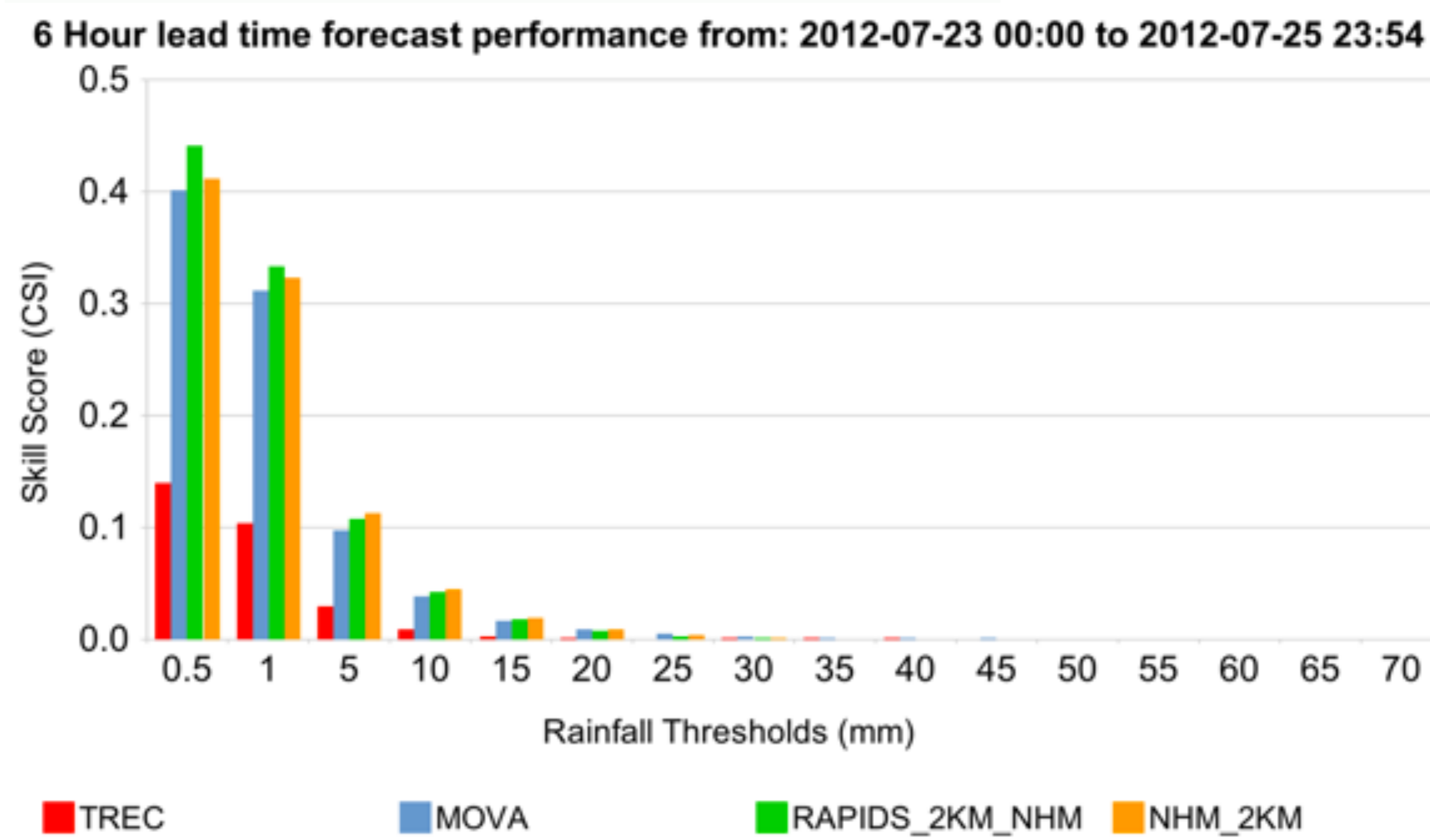


Performance

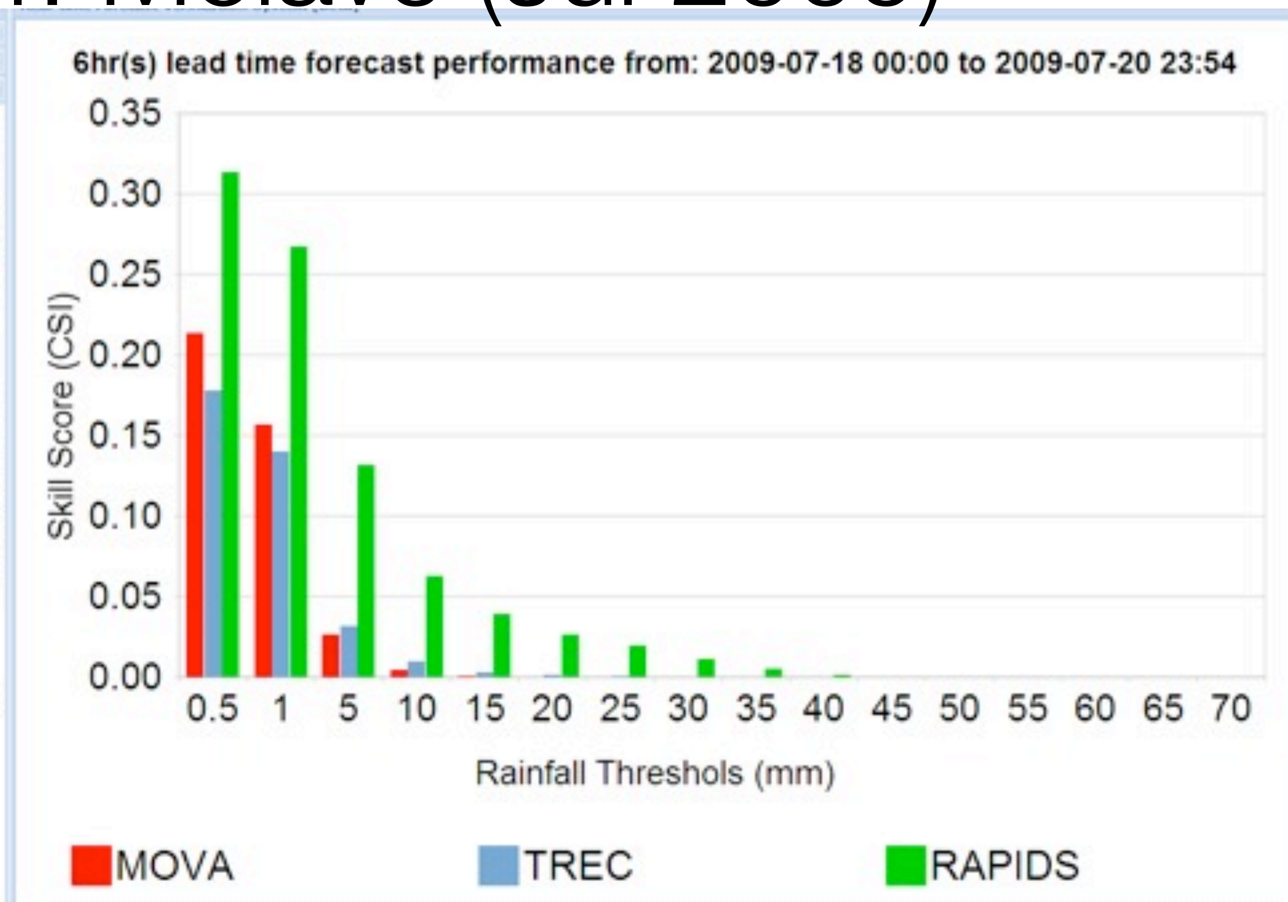
- Skill score (CSI)
  - CSI of T+1 to T+6 hr nowcast

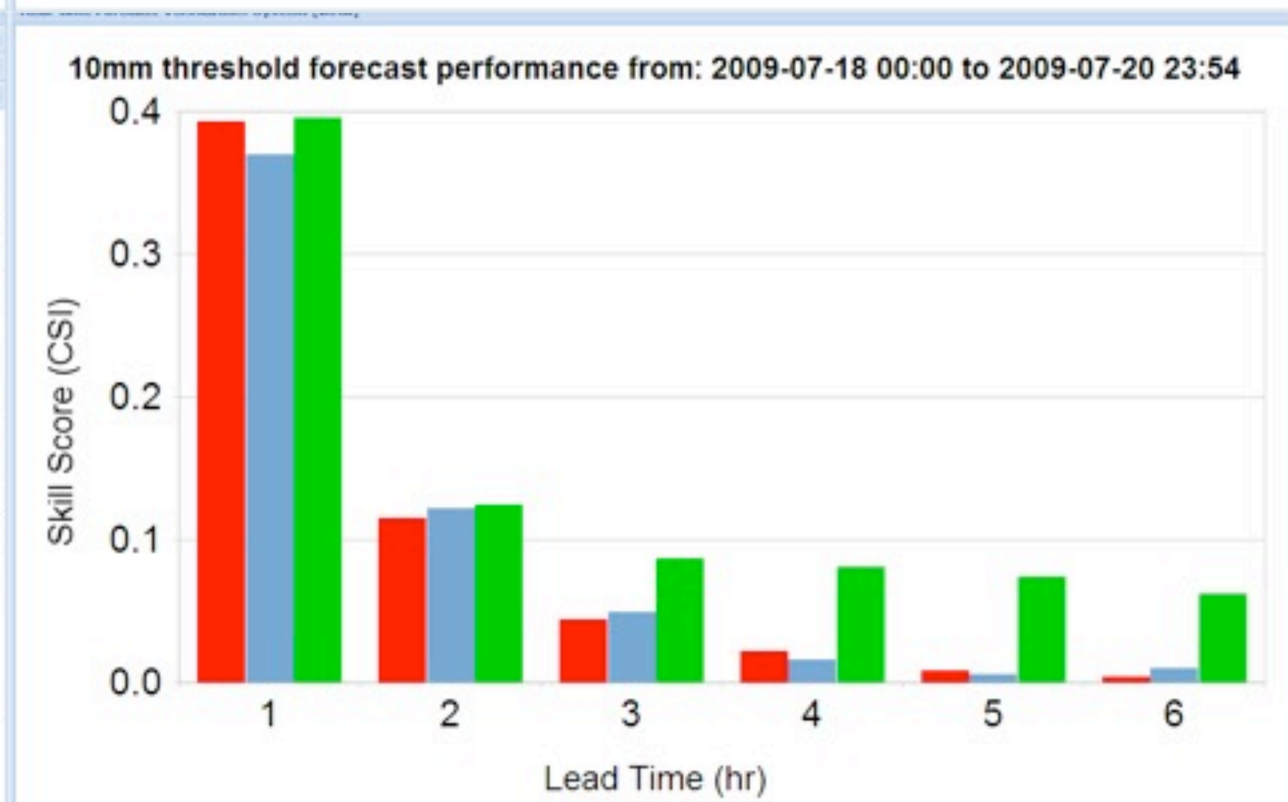


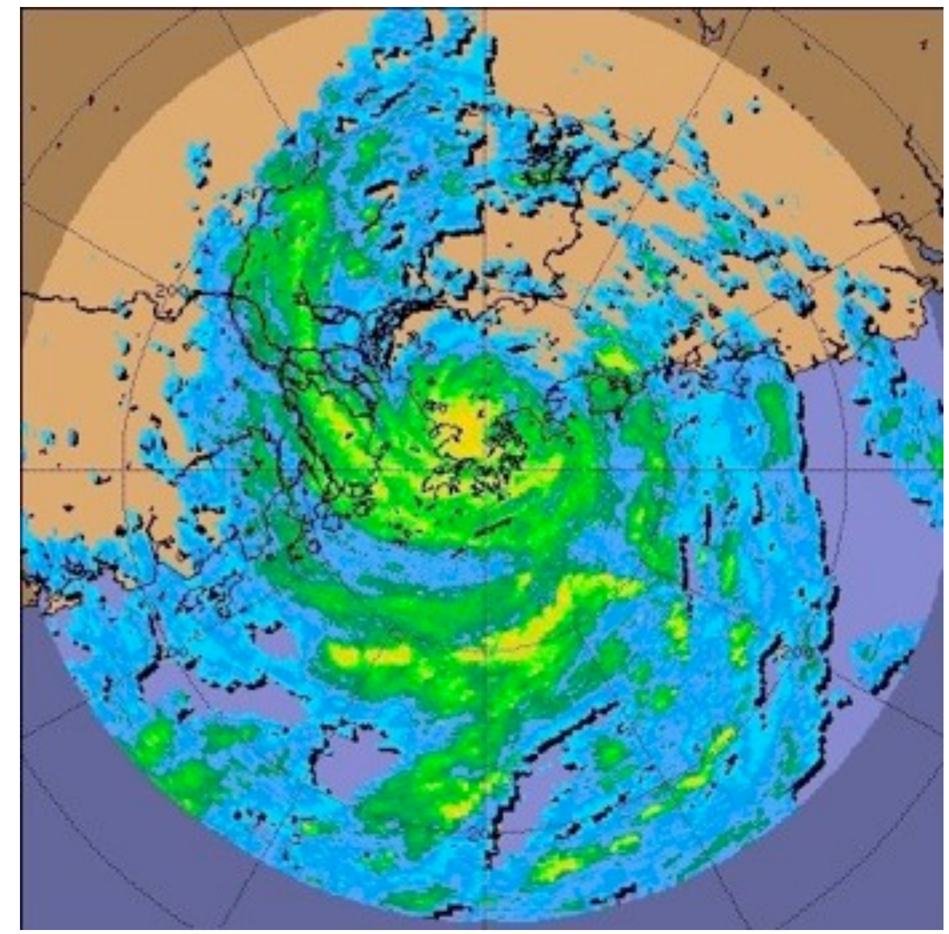
  - different rainfall thresholds at T+6 hr nowcast



T. Molave (Jul 2009)







Challenges for NWP TC intensity prediction

- Model resolution
- Initial condition
  - insufficient observations
  - errors using bogus approach
- Physical processes
  - air-sea interaction
  - interactions of complex processes across different scales
  - deficient representation of physical TC processes due to incomplete understanding

NWP TC intensity forecast

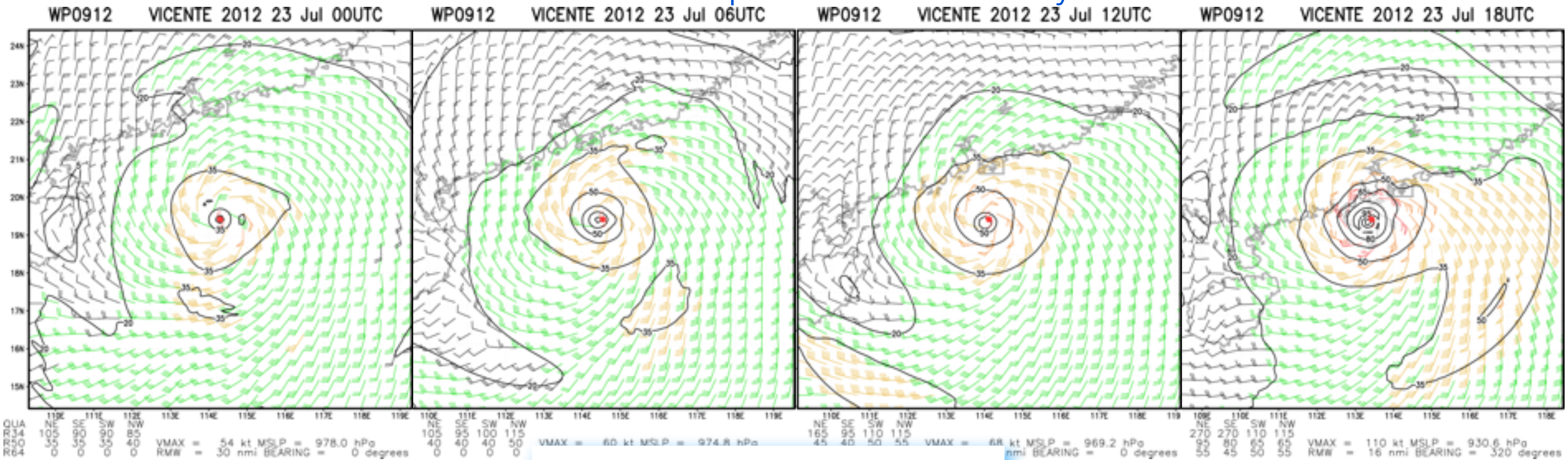
- central pressure
- maximum winds
  - or derived from pressure-wind empirical relationship
- wind distribution

statistical post-processing to generate warning of high winds, TC signal/warning probability

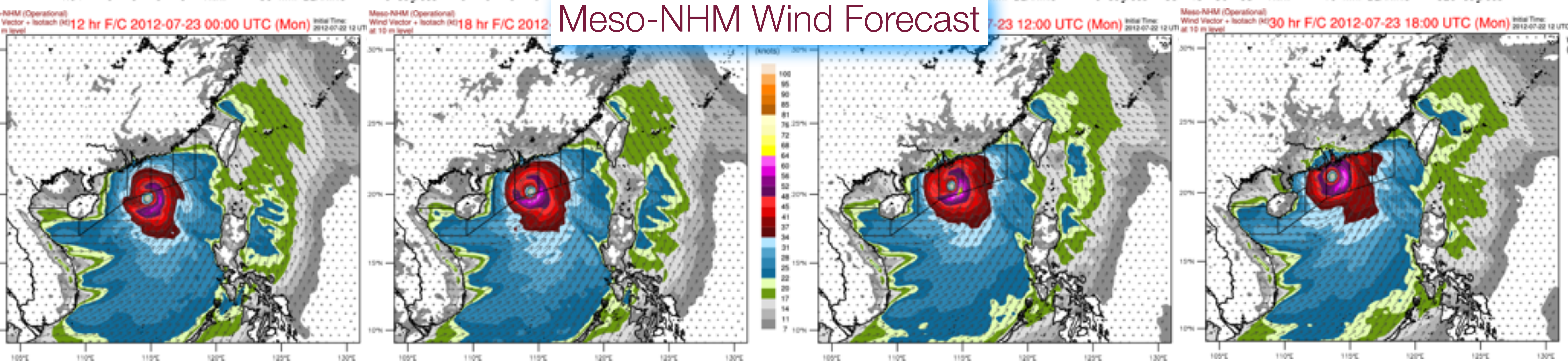
direct model outputs of wind forecast to predict high wind regions and development ??

ST Vicente
(00-18 UTC 2012-07-23)

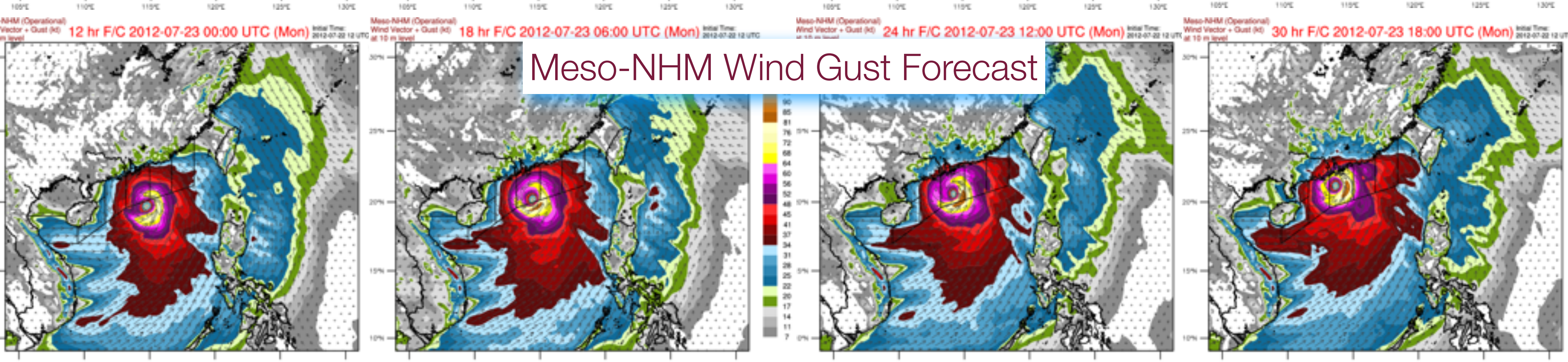
NOAA Multi-platform Wind Analysis



Meso-NHM Wind Forecast



Meso-NHM Wind Gust Forecast



Formulation of wind gust forecasts

- surface roughness and stability effects

$$u_{10,gust} = f(u_{10}, z, L)$$

u_{10} = wind speed at 10 m level
z = height
L = Monin Obukhov length scale

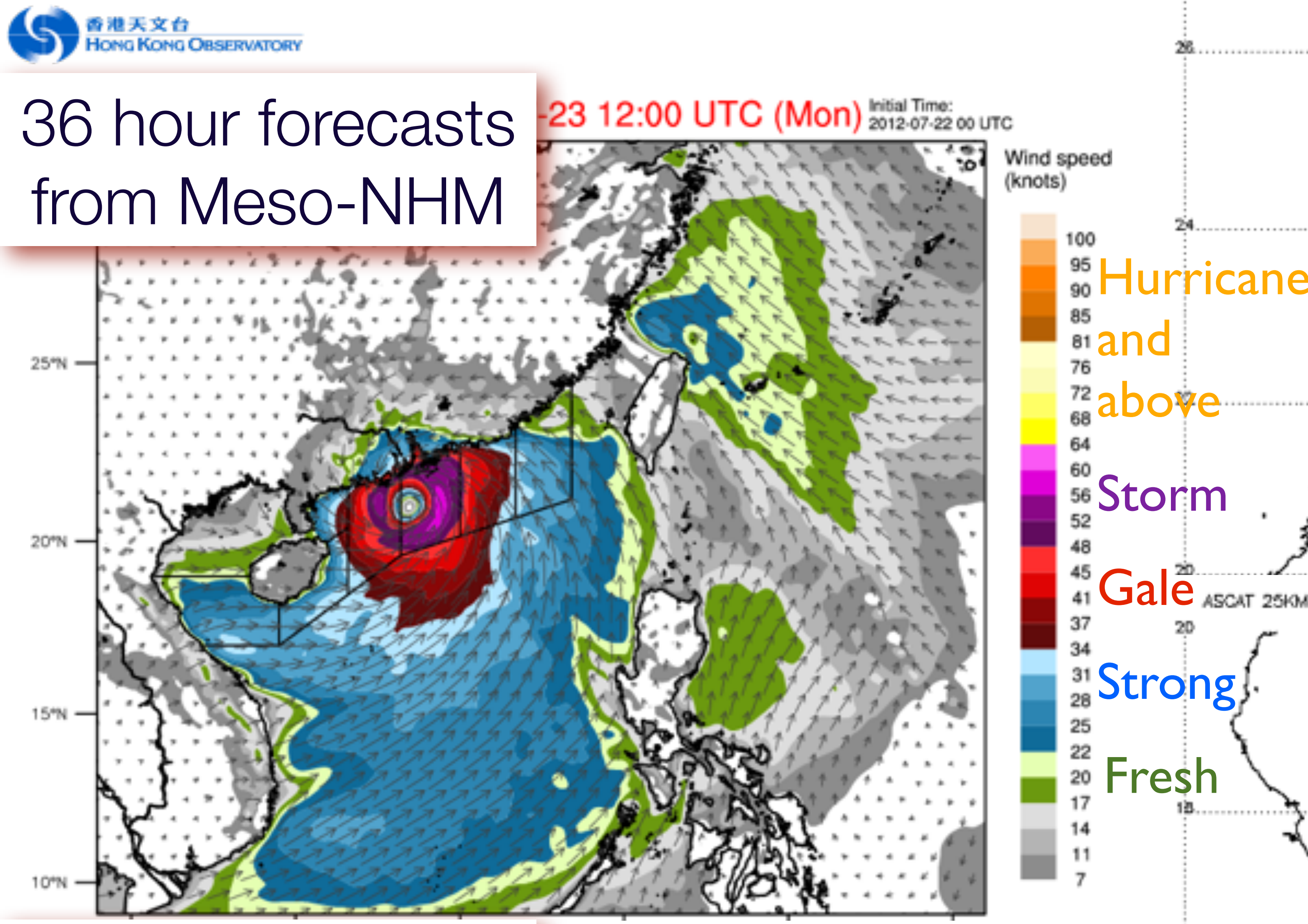
- convective component derived from low-level wind shear effects

$$u_{10,gust} = \alpha \max(0, u_{850} - u_{950})$$

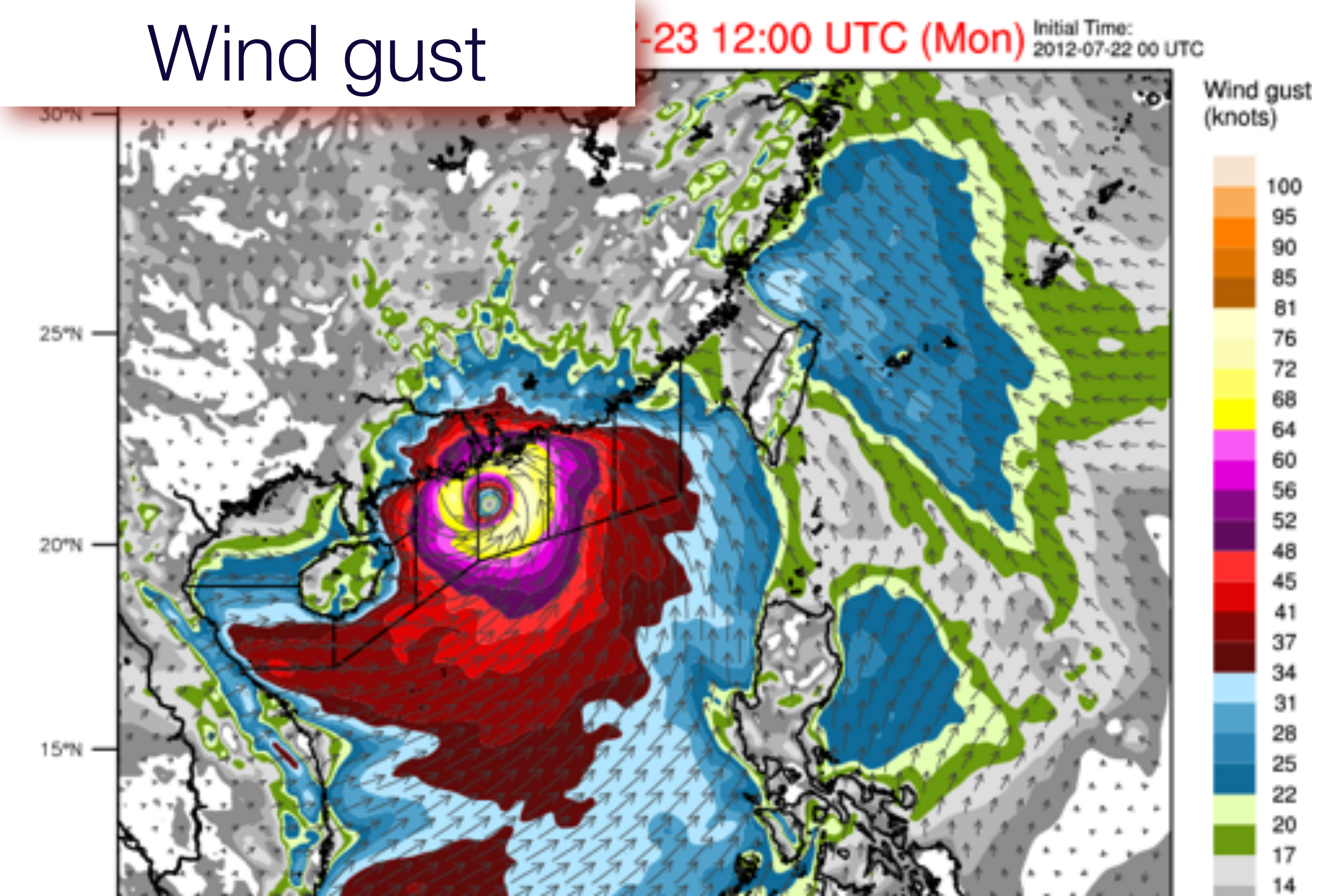
$$\alpha \sim 0.6$$

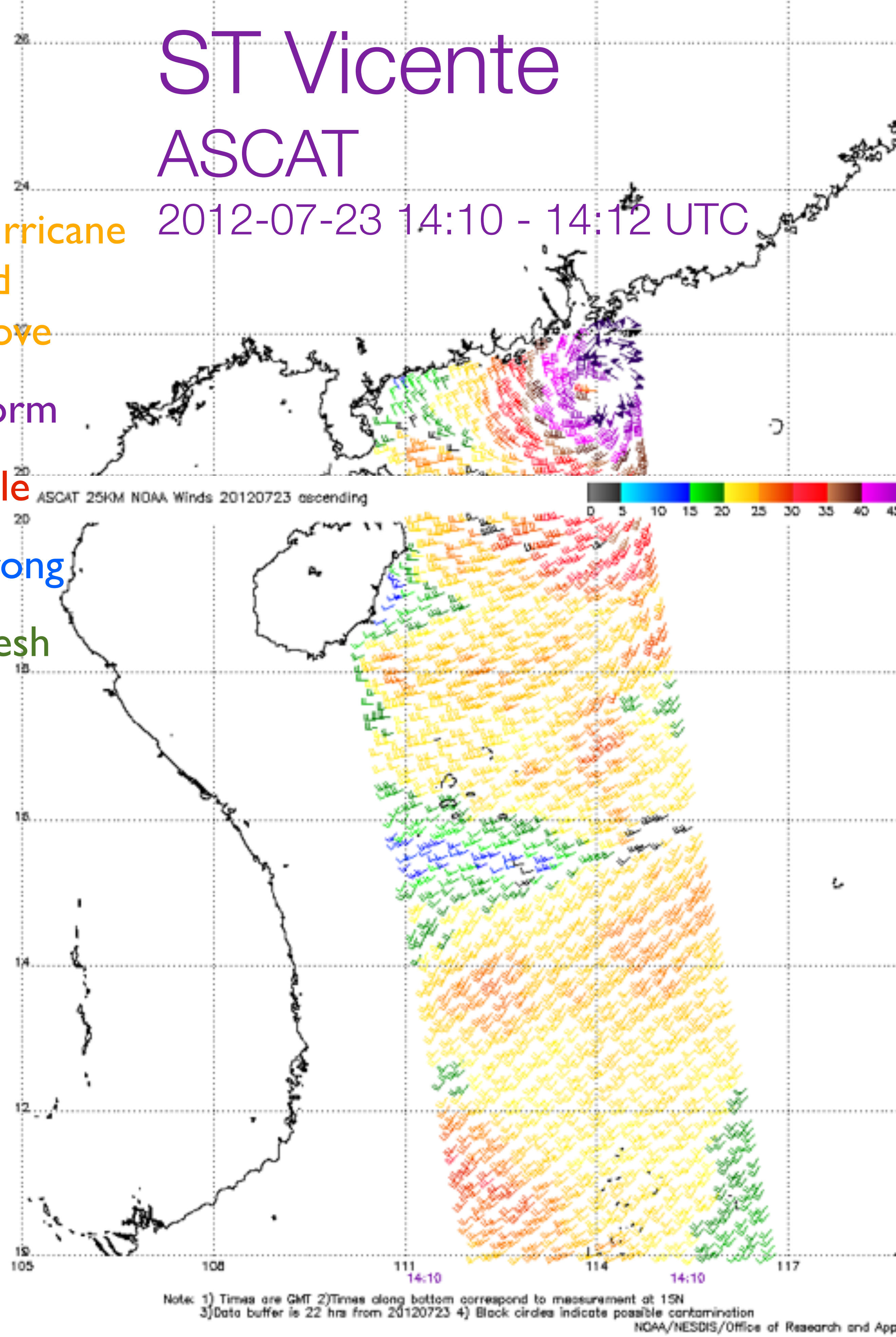
ST Vicente
ASCAT
2012-07-23 14:10 - 14:12 UTC

36 hour forecasts from Meso-NHM



Wind gust

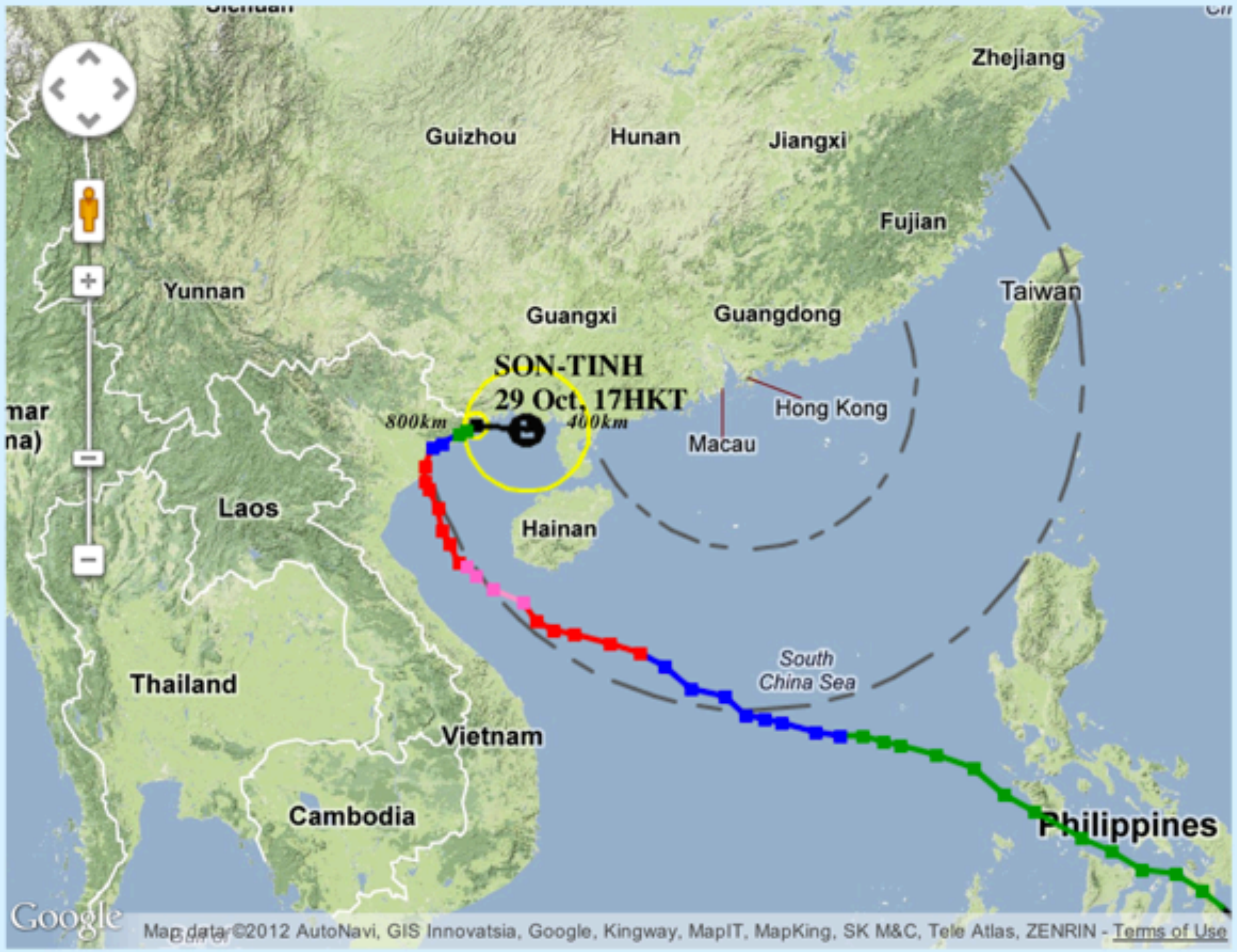




Tropical cyclone Son-Tinh

Tropical Cyclone Track Information

Tropical Cyclone: SON-TINH



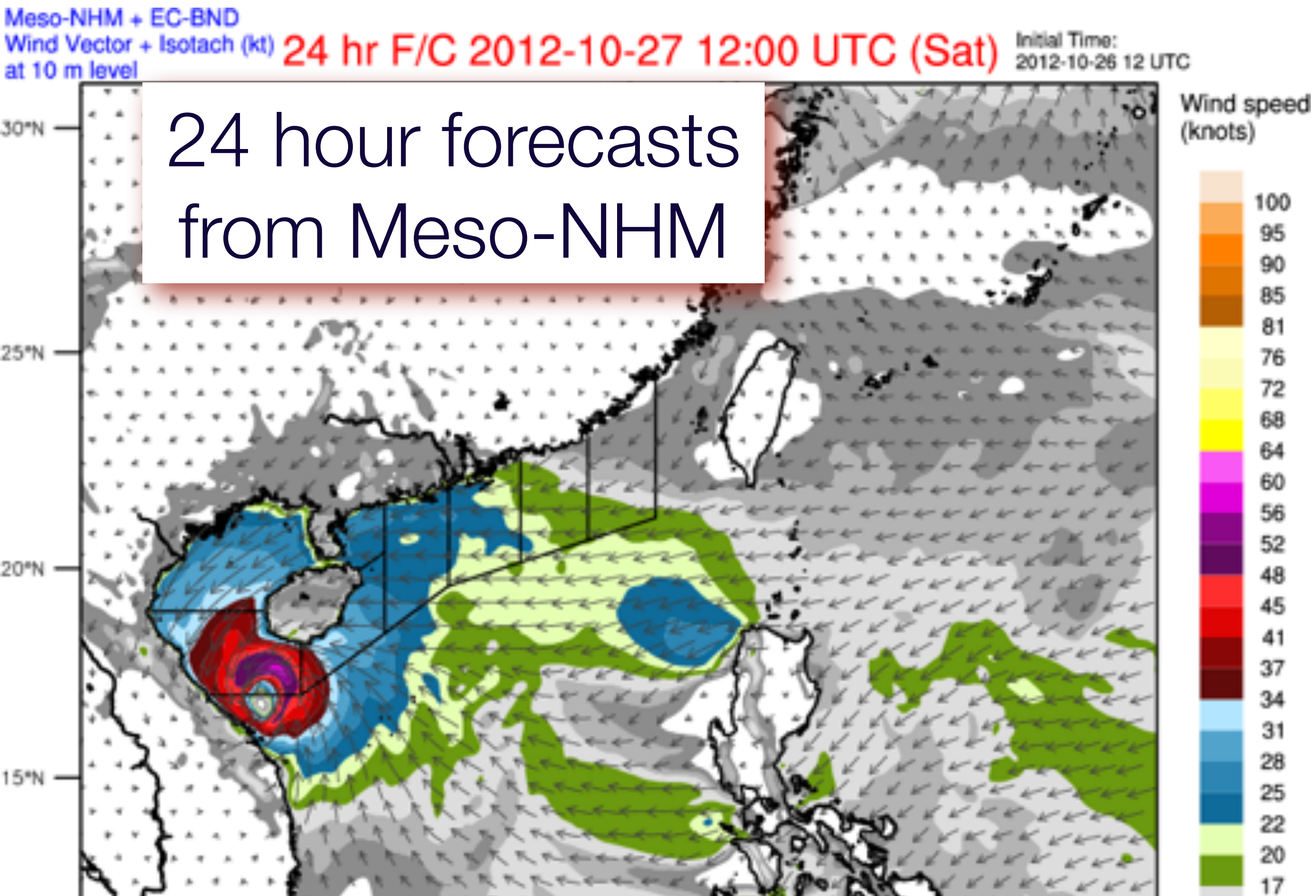
Name: Tropical Depression SON-TINH
Date: 29 Oct 2012 **Time:** 17 HKT
Position: 21.4 N, 107.8 E (about 670 km west of Hong Kong)
Maximum sustained wind near centre: 55 km/h

ST Son-Tinh

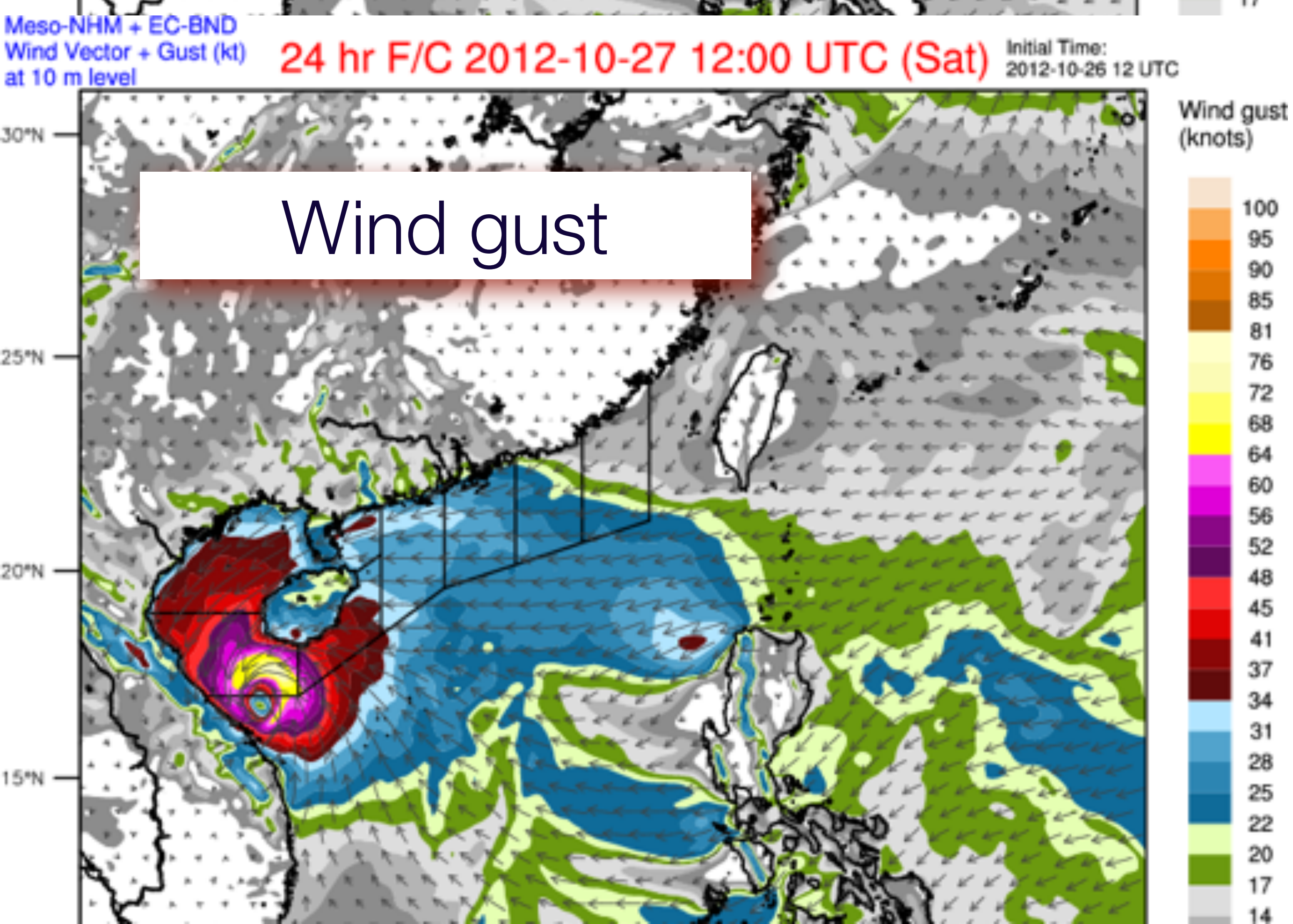
ASCAT

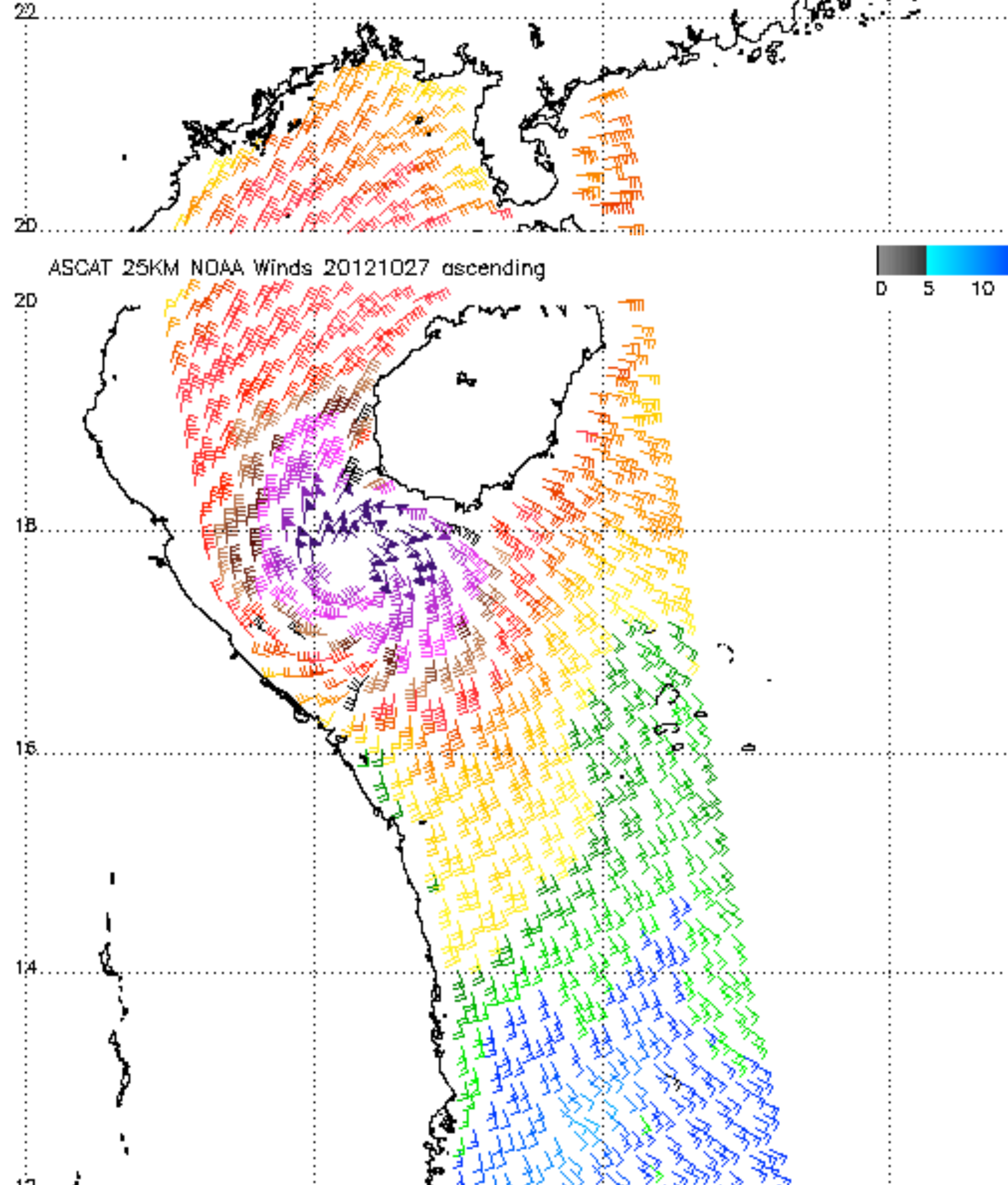
2012-10-27 14:24 - 14:26 UTC

24 hour forecasts from Meso-NHM

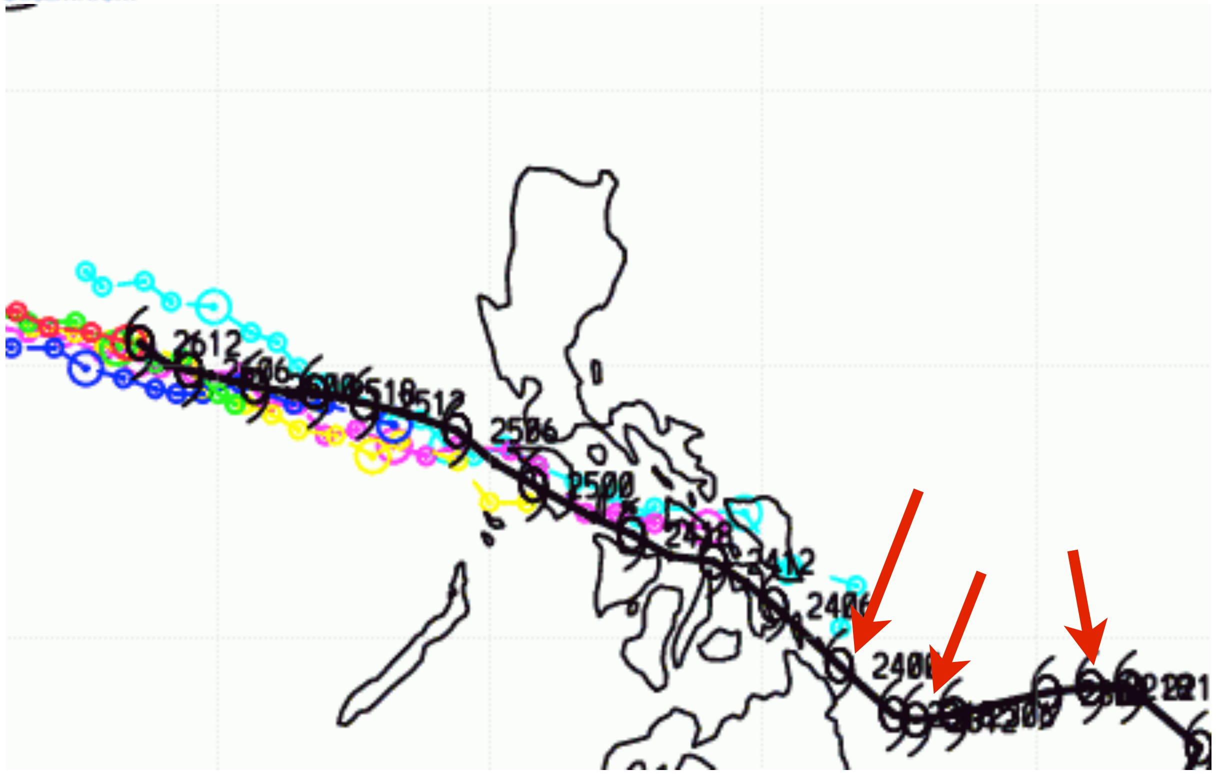


Wind gust





When Son-tinh crossed the Philippines ...

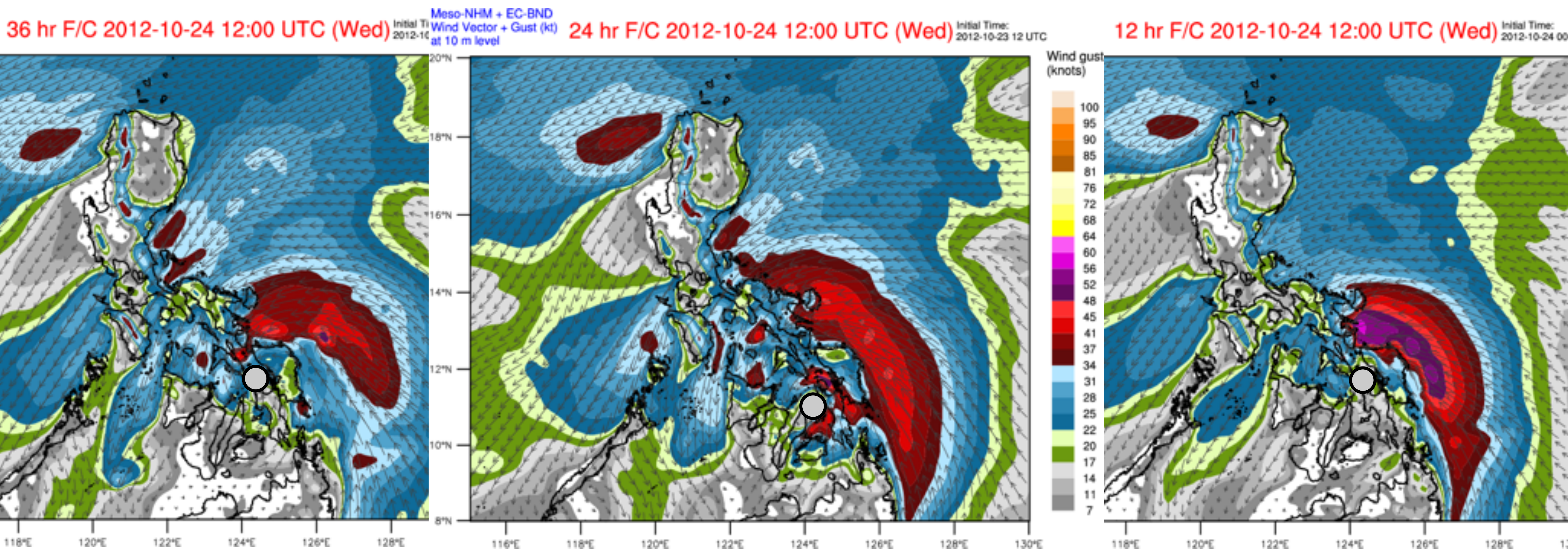


Forecast runs from 23/00, 23/12Z and 24/00Z

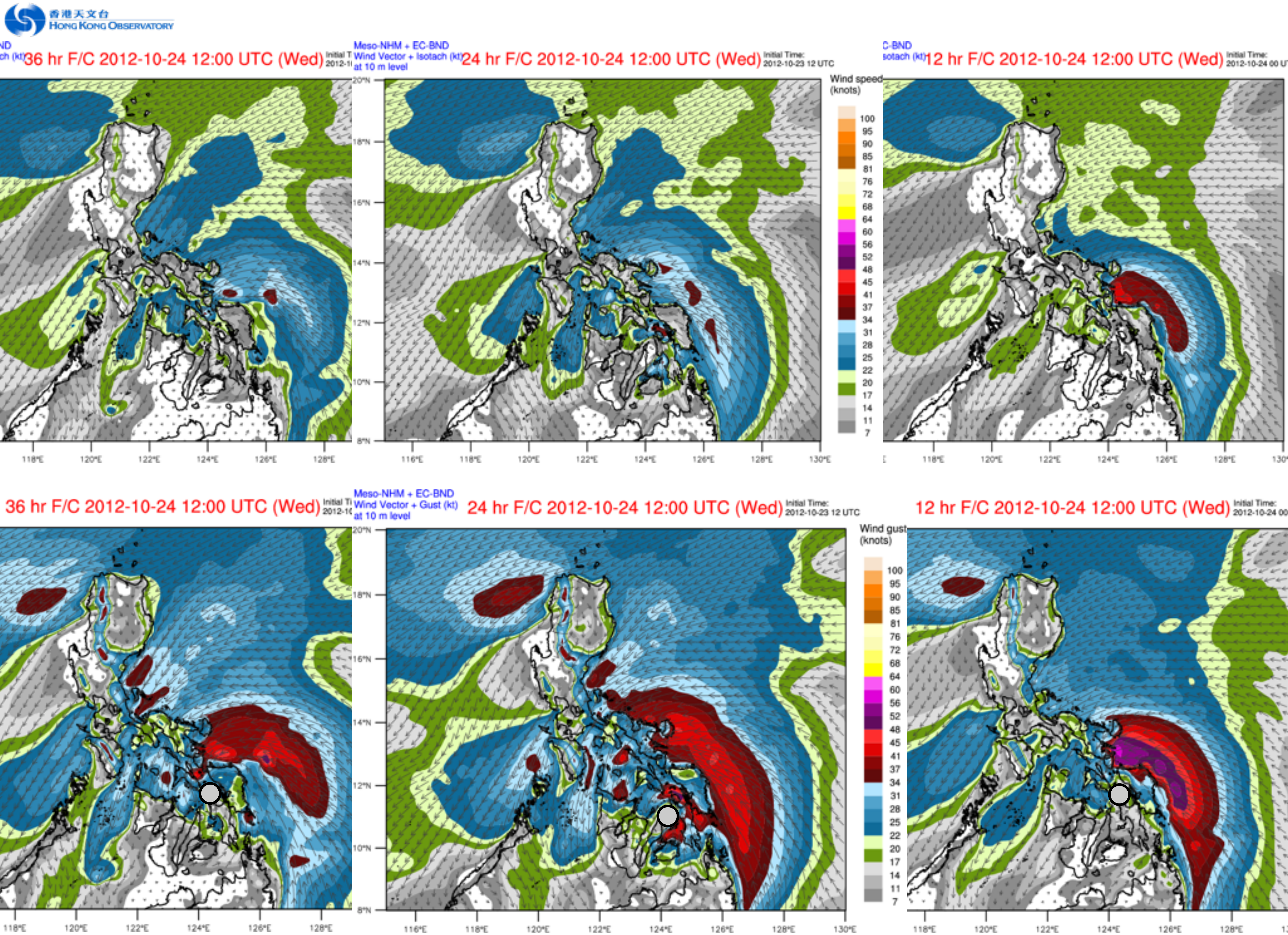
HKO warning intensity at 24/12 Z: 65 km/hr (TS)

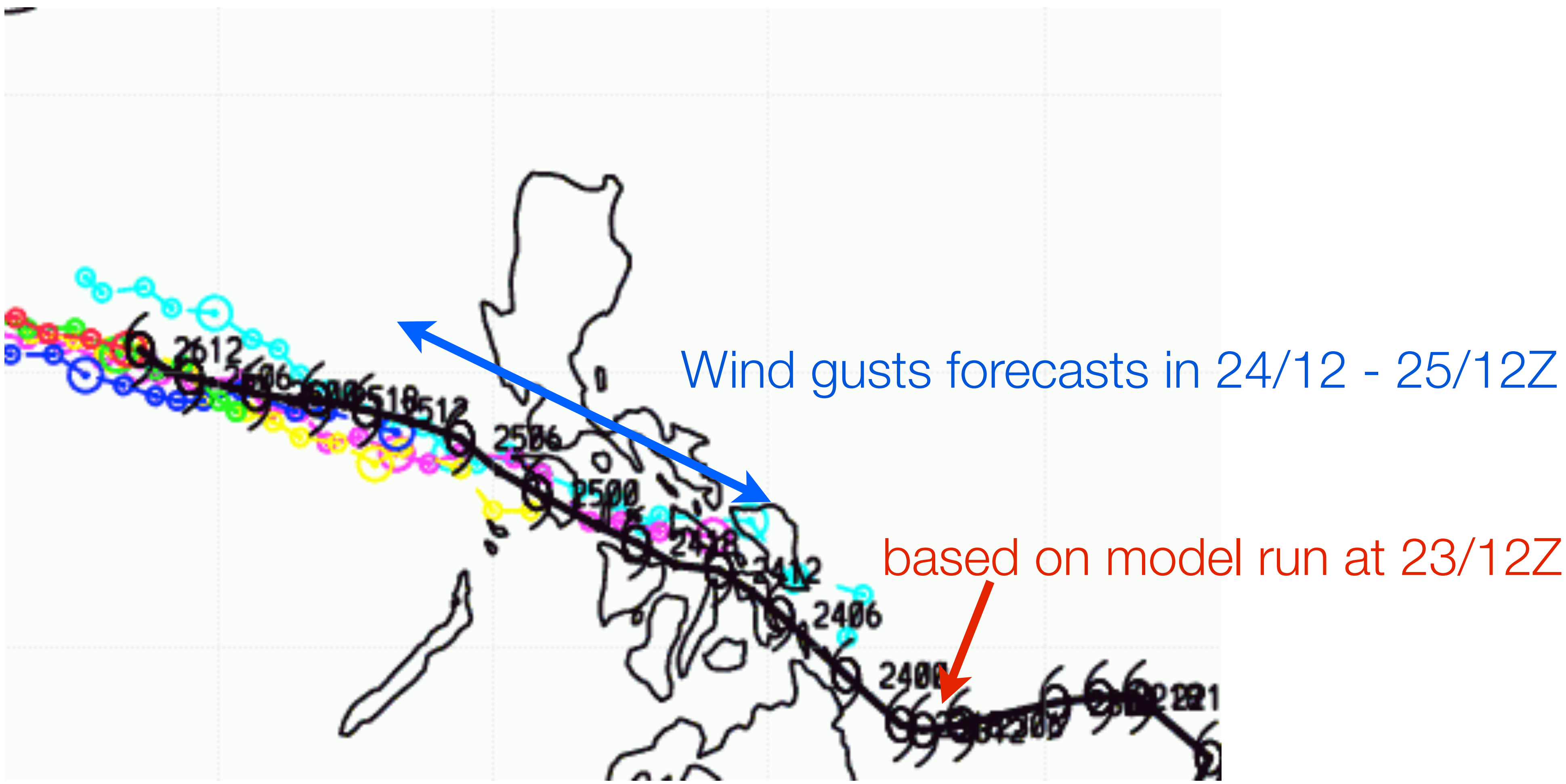
Forecast centres from all 3 model runs valid at 24/12 Z

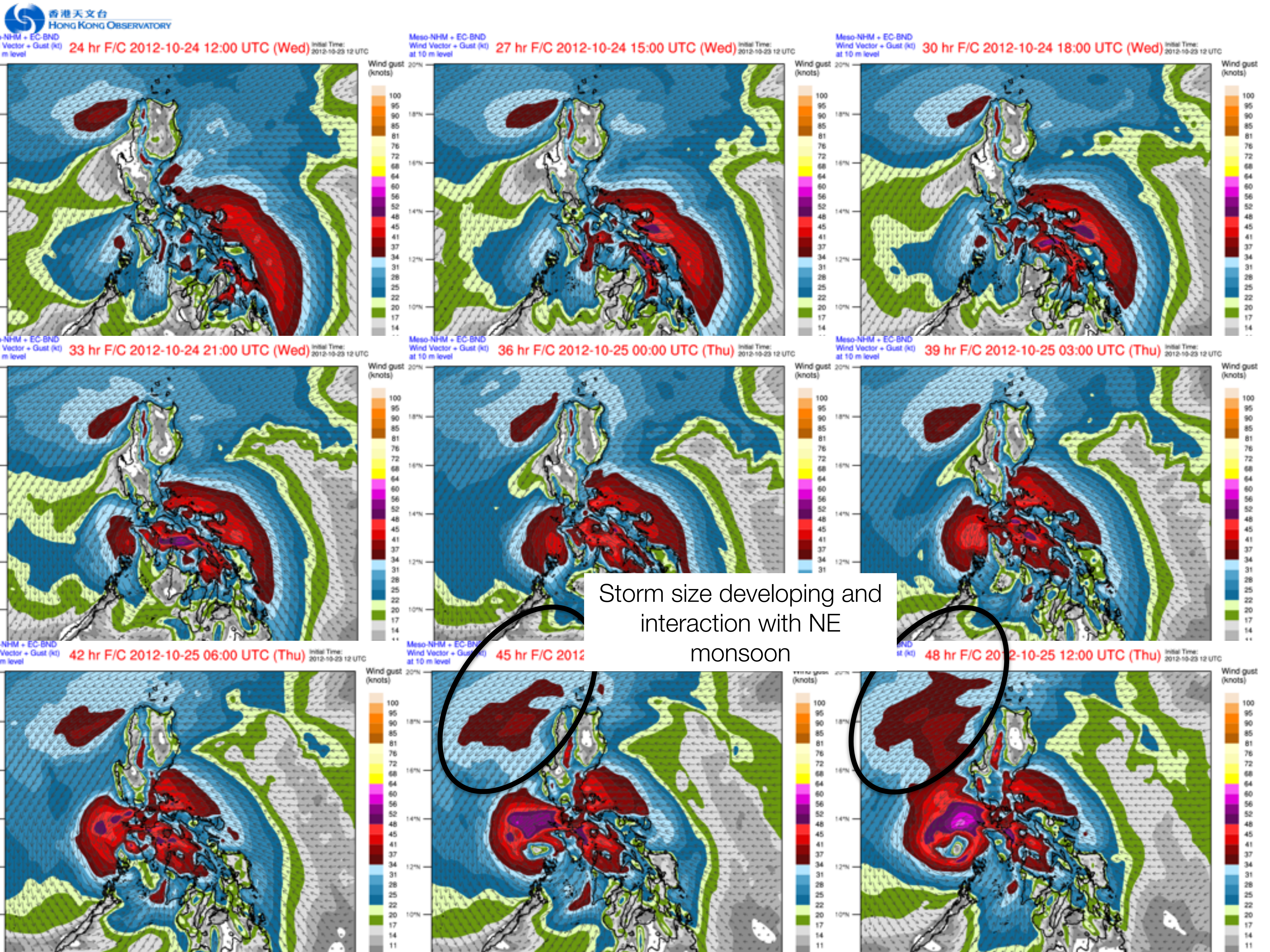
Forecast wind gust distributions



Compare forecast winds at 10 m (top) and wind gust (bottom) in next slide ...


香港天文台
Hong Kong Observatory
36 hr F/C 2012-10-24 12:00 UTC (Wed)
Meso-NHM + EC-BND
Wind Vector + Isotach (kt)
at 10 m level
24 hr F/C 2012-10-24 12:00 UTC (Wed)
Initial Time: 2012-10-23 12 UTC
Wind speed (knots)
12 hr F/C 2012-10-24 12:00 UTC (Wed)
36 hr F/C 2012-10-24 12:00 UTC (Wed)
Meso-NHM + EC-BND
Wind Vector + Gust (kt)
at 10 m level
24 hr F/C 2012-10-24 12:00 UTC (Wed)
Initial Time: 2012-10-23 12 UTC
Wind gust (knots)
12 hr F/C 2012-10-24 12:00 UTC (Wed)


Wind gusts forecasts in 24/12 - 25/12Z
based on model run at 23/12Z
2612
2506
2500
2418
2412
2406
2400

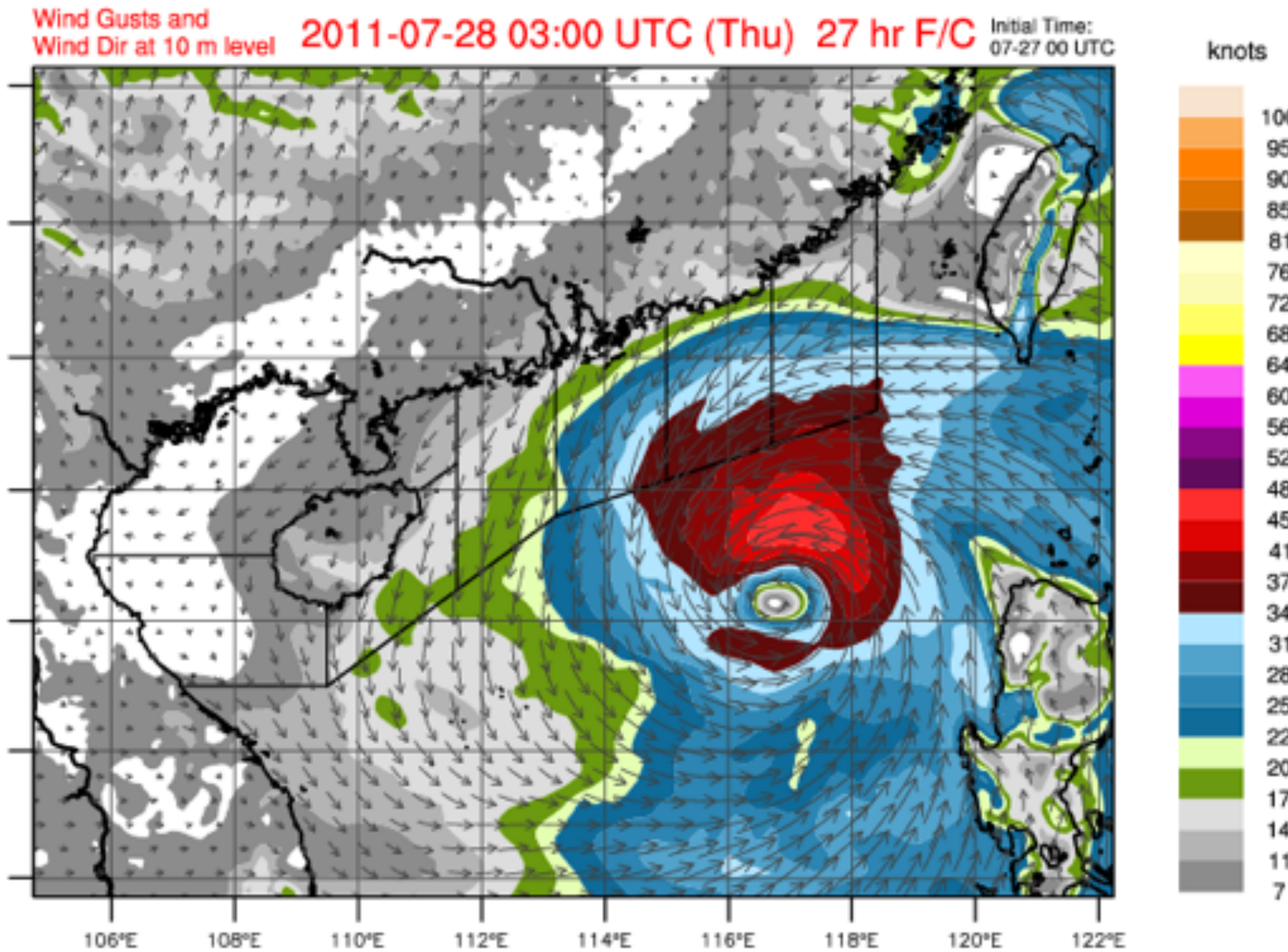

香港天文台
Hong Kong Observatory
24 hr F/C 2012-10-24 12:00 UTC (Wed)
27 hr F/C 2012-10-24 15:00 UTC (Wed)
30 hr F/C 2012-10-24 18:00 UTC (Wed)
33 hr F/C 2012-10-24 21:00 UTC (Wed)
36 hr F/C 2012-10-25 00:00 UTC (Thu)
39 hr F/C 2012-10-25 03:00 UTC (Thu)
42 hr F/C 2012-10-25 06:00 UTC (Thu)
48 hr F/C 20 2-10-25 12:00 UTC (Thu)
Meso-NHM + EC-BND
Wind Vector + Gust (kt)
at 10 m level
Wind gust (knots)
Storm size developing and interaction with NE monsoon

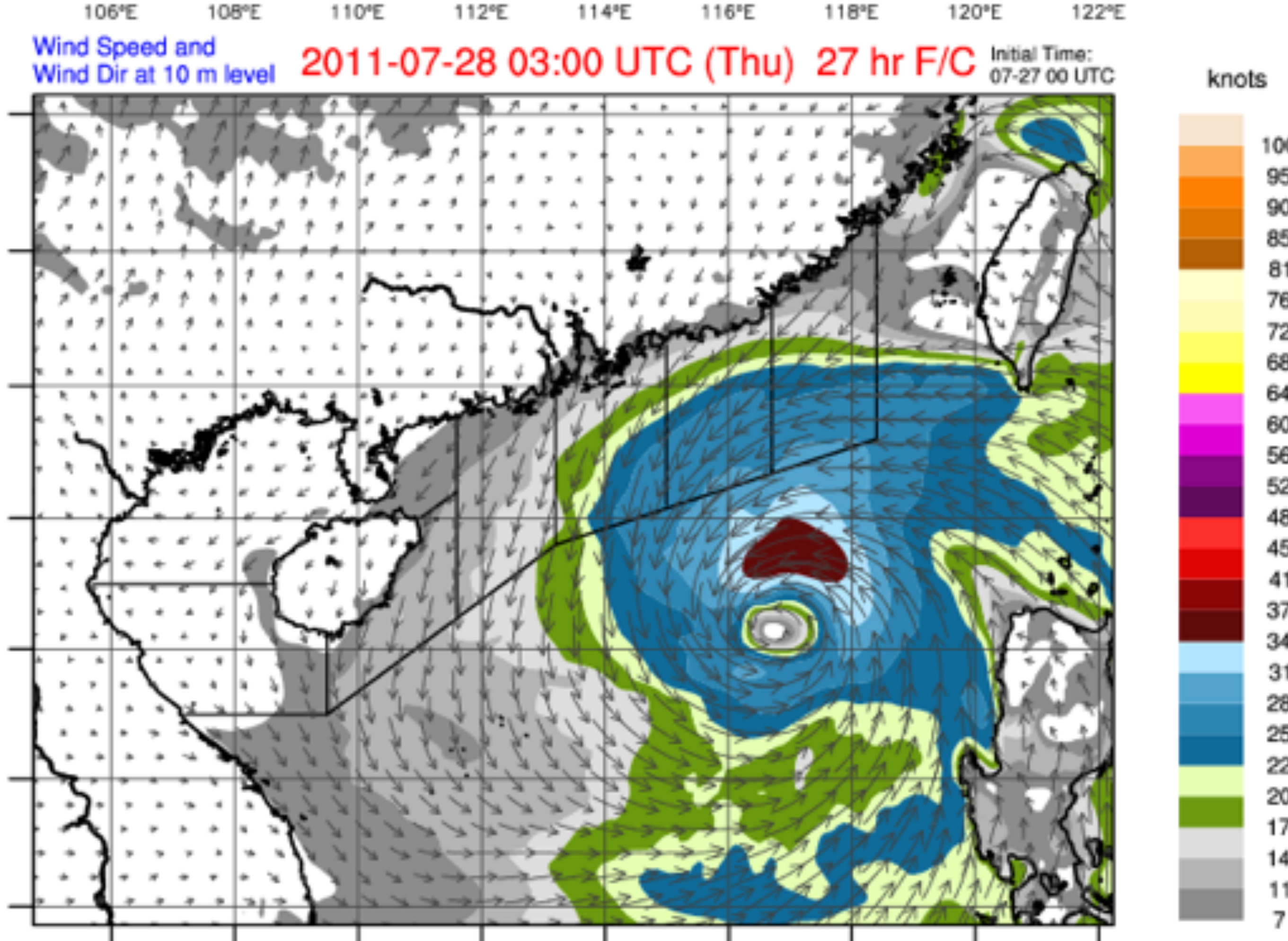
Meso-NHM Forecast Wind Gusts and Wind Vectors at 10 m level

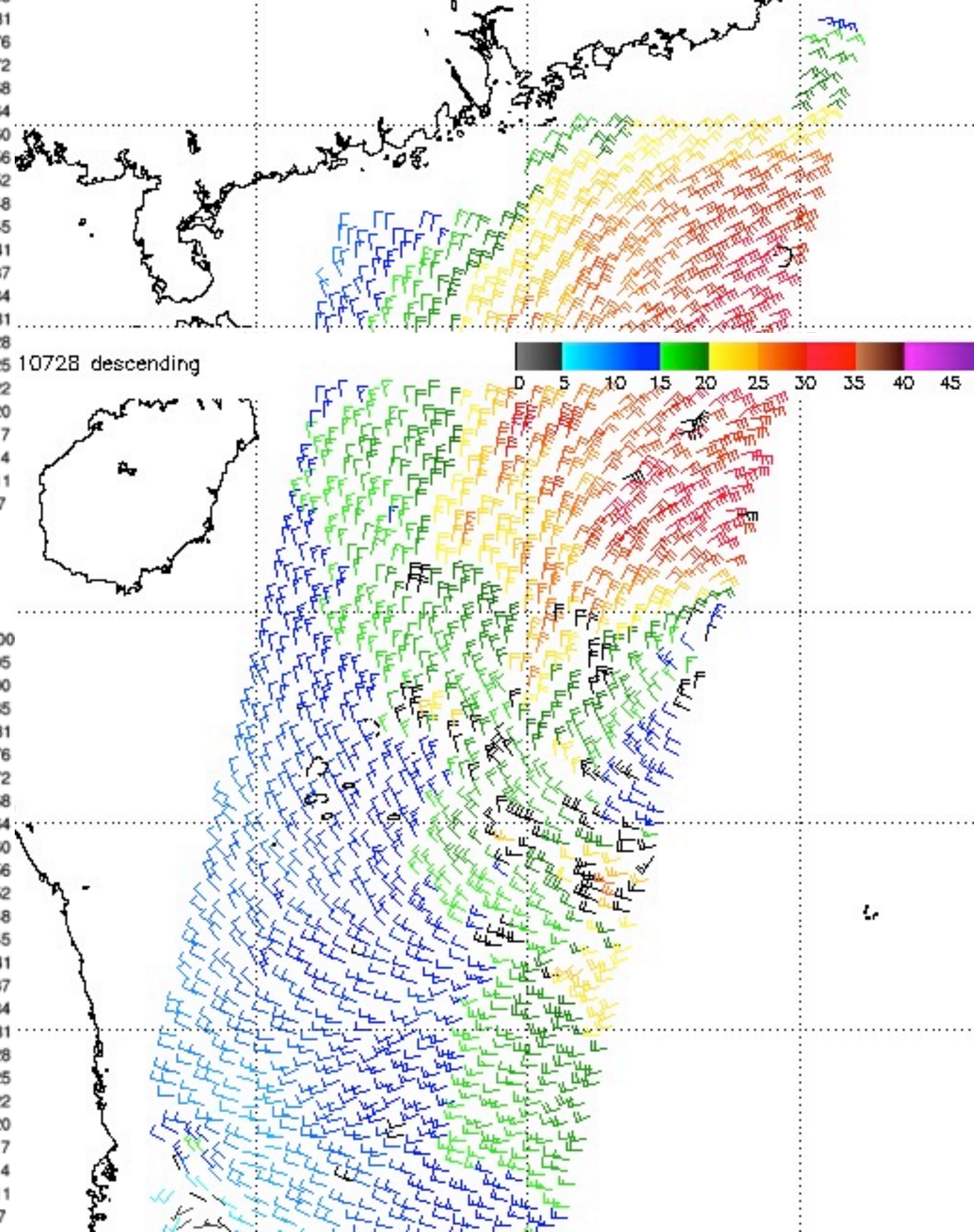
TC Nock-Ten

ASCAT

2011-07-28 02:30 UTC



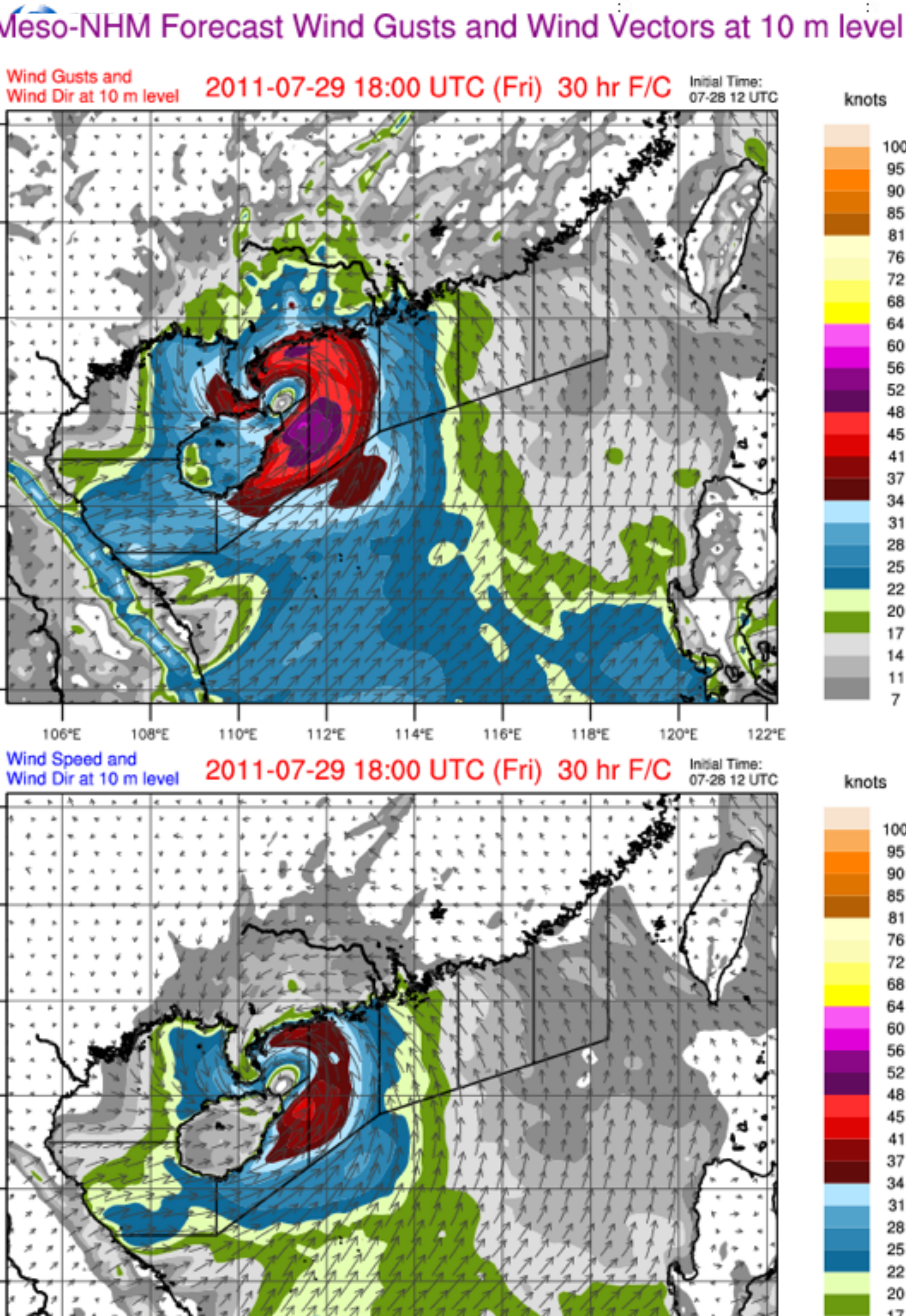


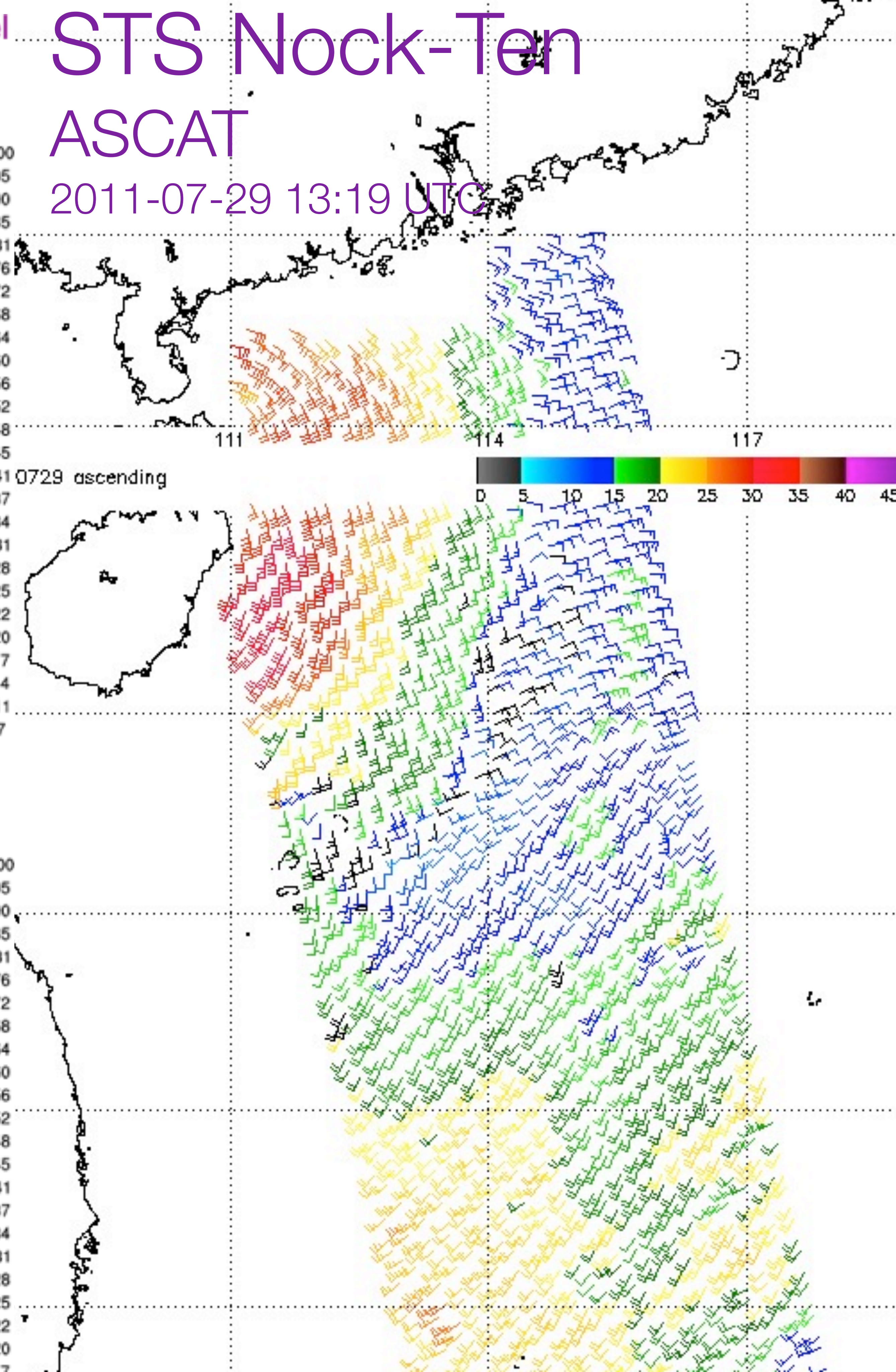


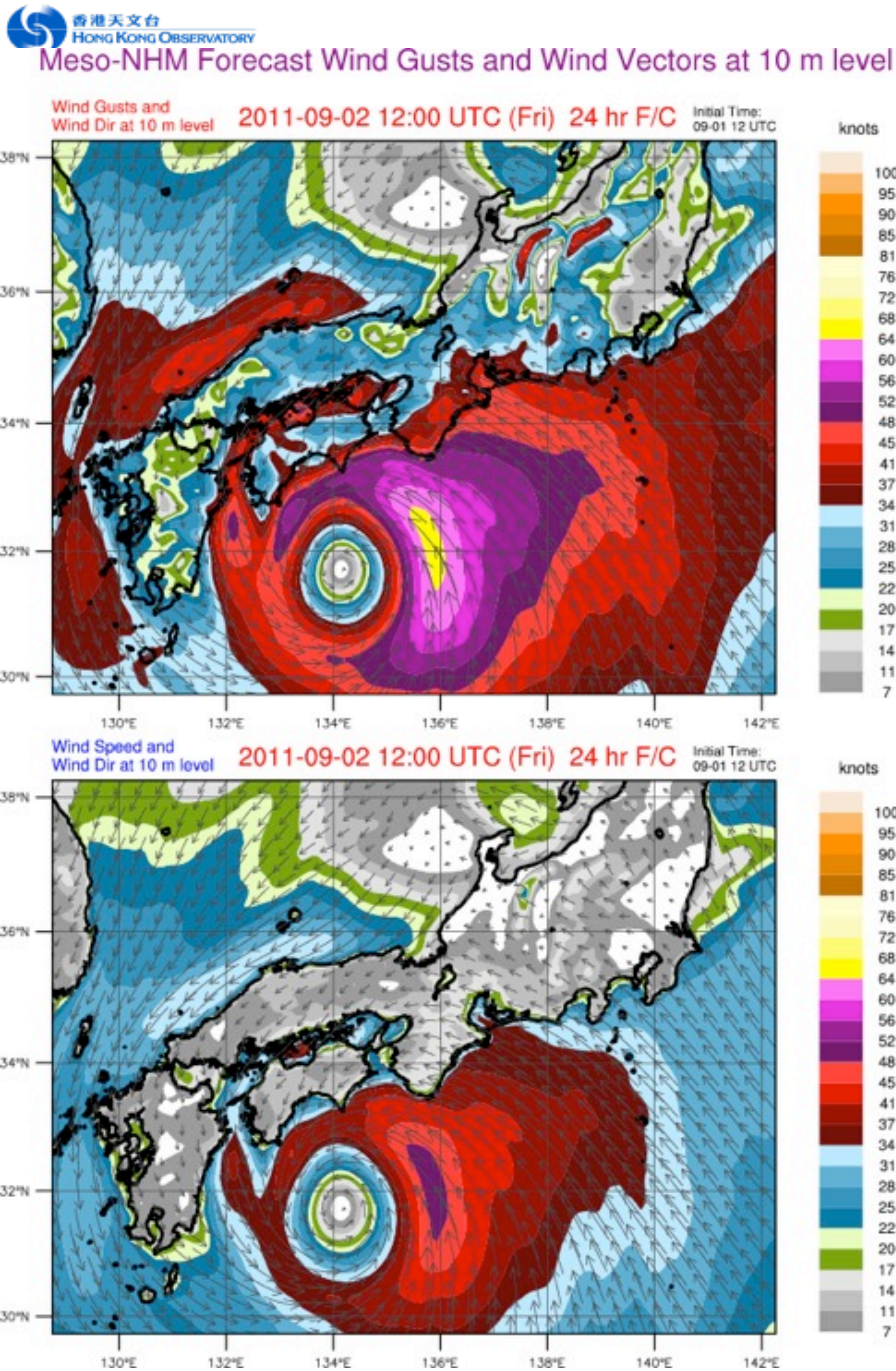
STS Nock-Ten

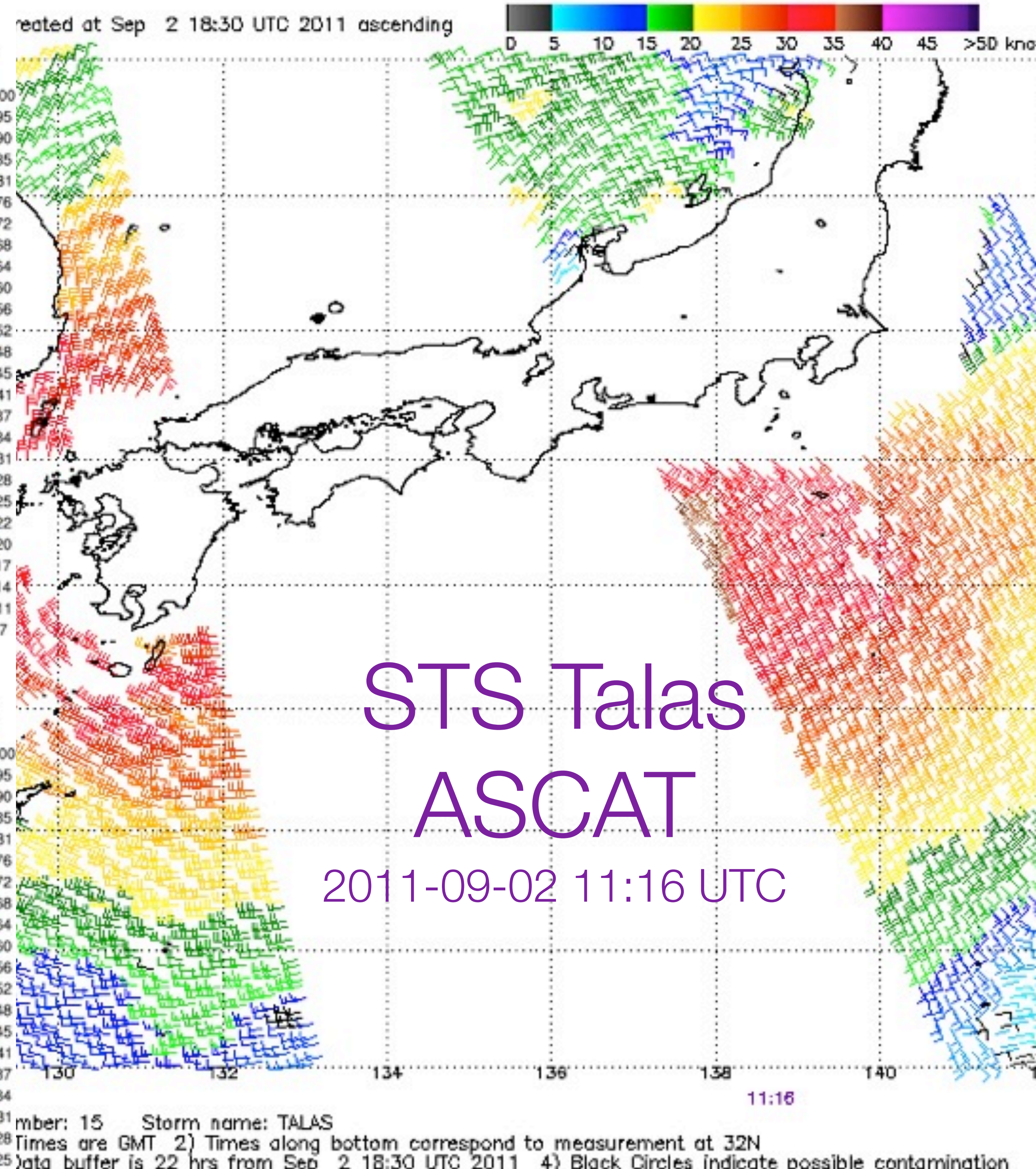
ASCAT

2011-07-29 13:19 UTC



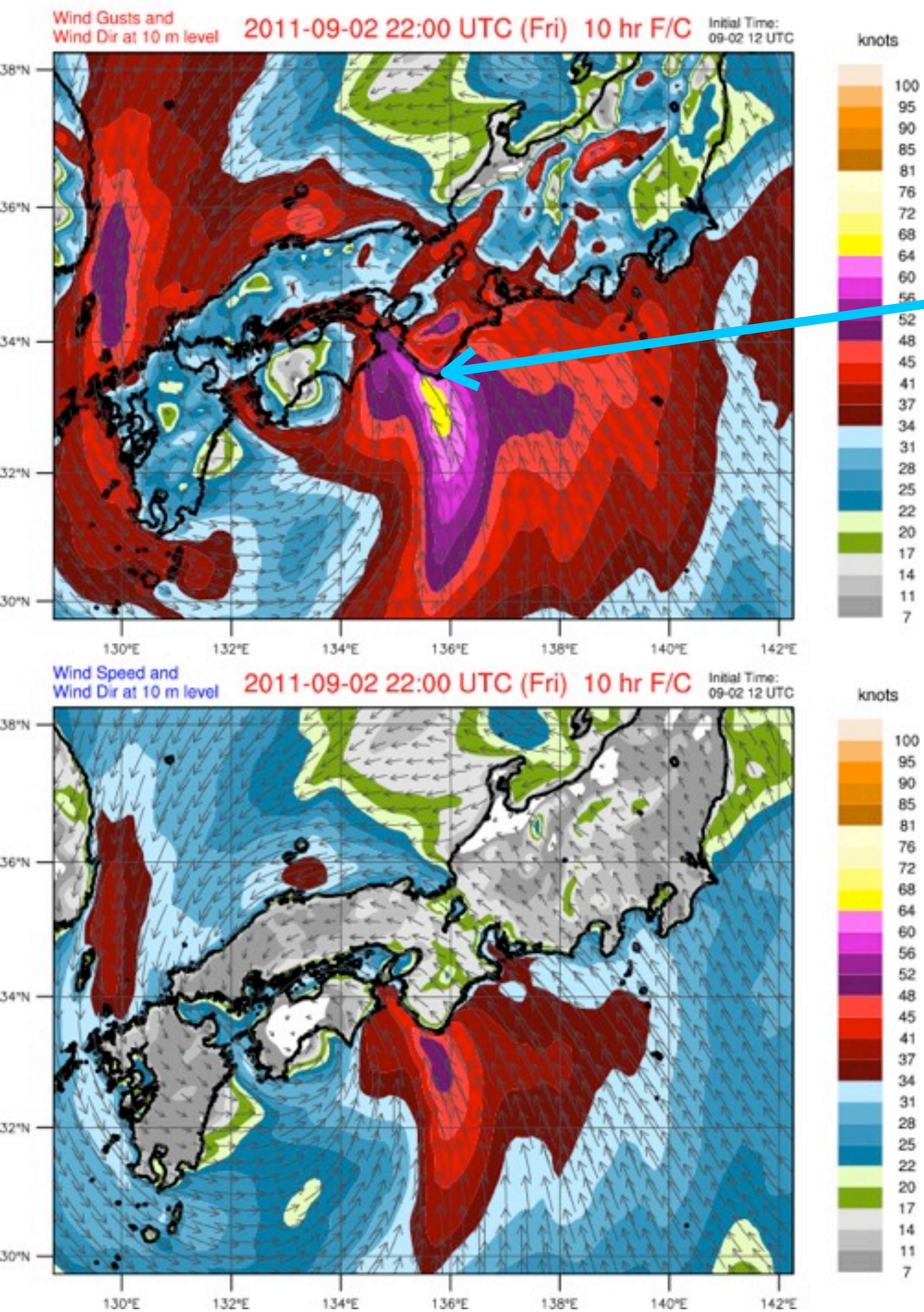






STS Talas
ASCAT
2011-09-02 11:16 UTC

Meso-NHM Forecast Wind Gusts and Wind Vectors at 10 m level

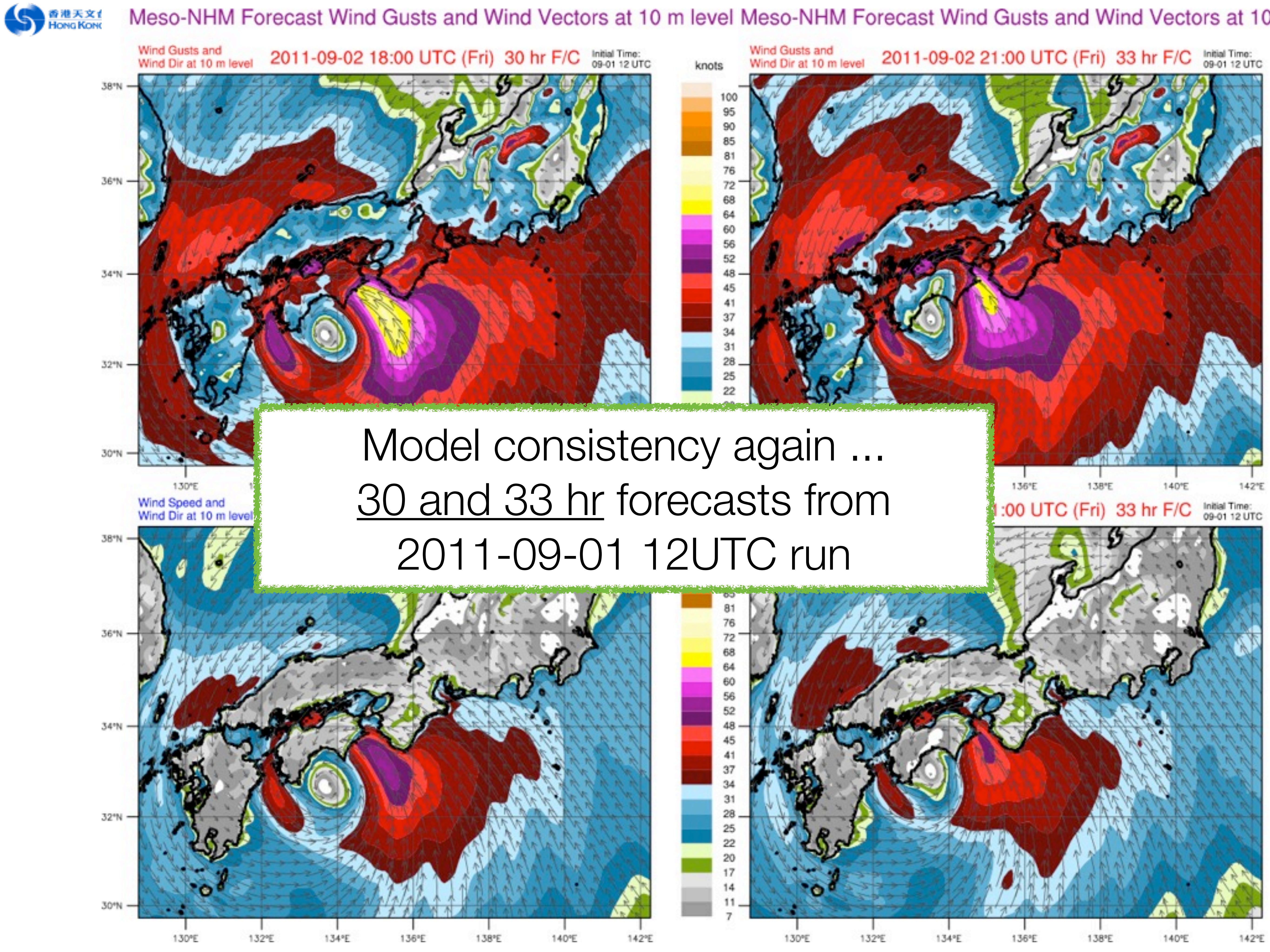


Nanki-shirahama

Recorded max. instantaneous wind 35.0 m/s (SE) 0630 JST

10 hr forecast from Meso-NHM

2011-09-02 12UTC run



Model consistency again ...

<u>30 and 33 hr</u> forecasts from

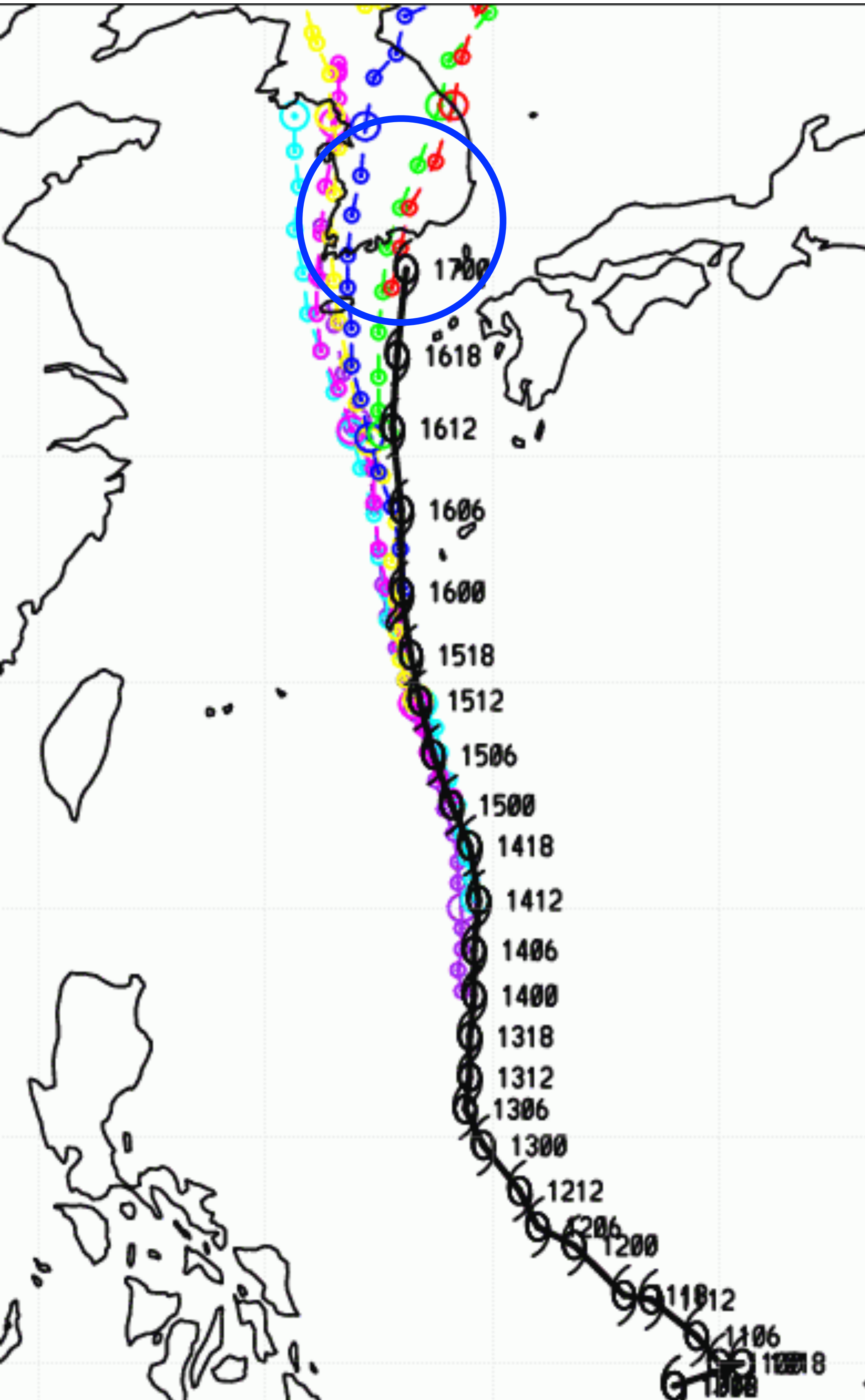
2011-09-01 12UTC run

香港天文台 Hong Kong Observatory

ST Sanba

Busan

winds at ~ 97 mph (84 knots)

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Terrifying typhoon hits South Korea with 100mph winds so strong rocks are sent flying through the air

By PHIL VINTER

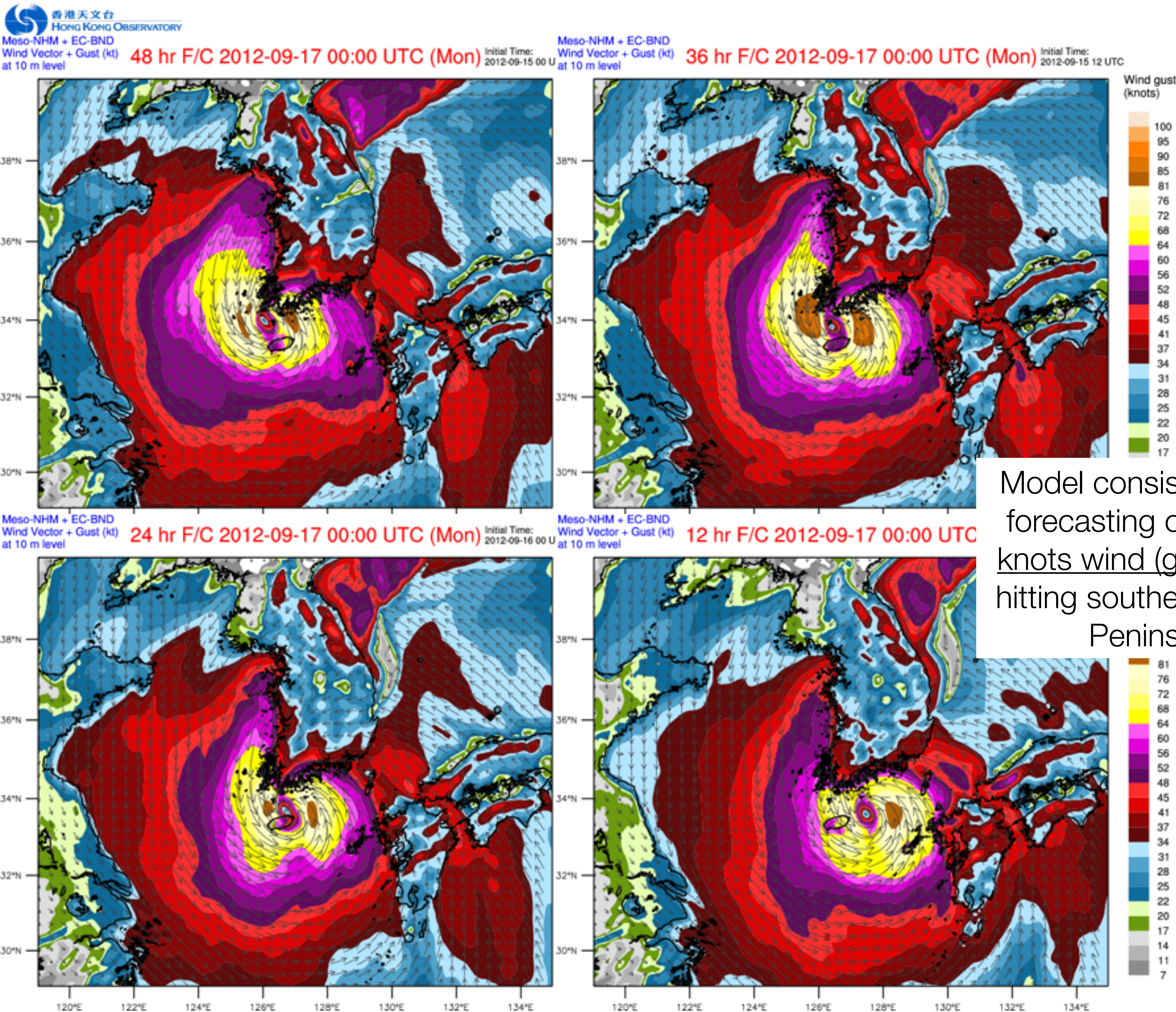
PUBLISHED: 10:07 GMT, 17 September 2012 | UPDATED: 10:18 GMT, 17 September 2012

Comments (7) | Share +1 4 Tweet 19 Like 451

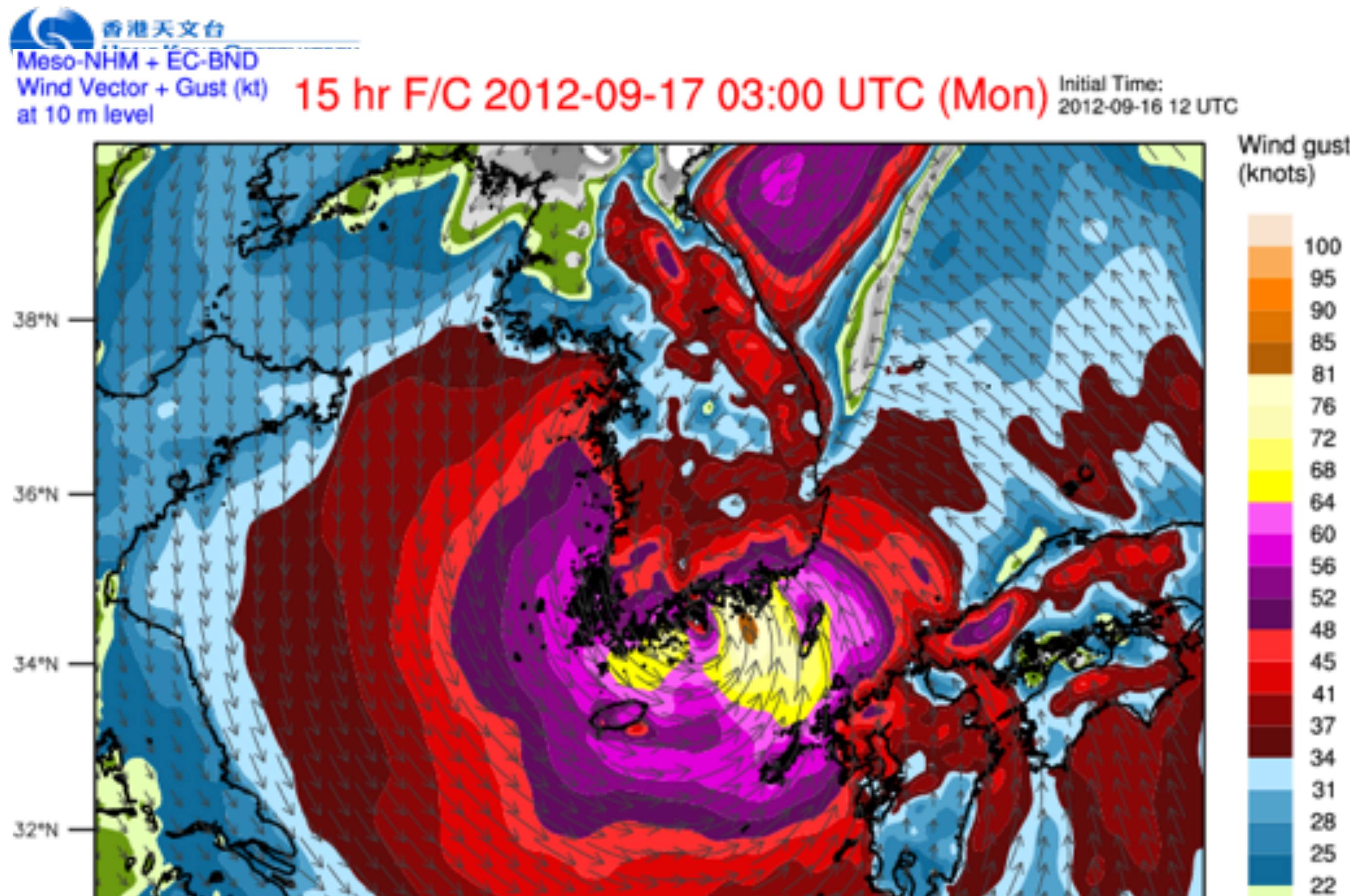
A typhoon ripped through the coast of South Korea this morning with powerful winds and heavy rain causing the death of at least one person and leaving scores of others homeless .

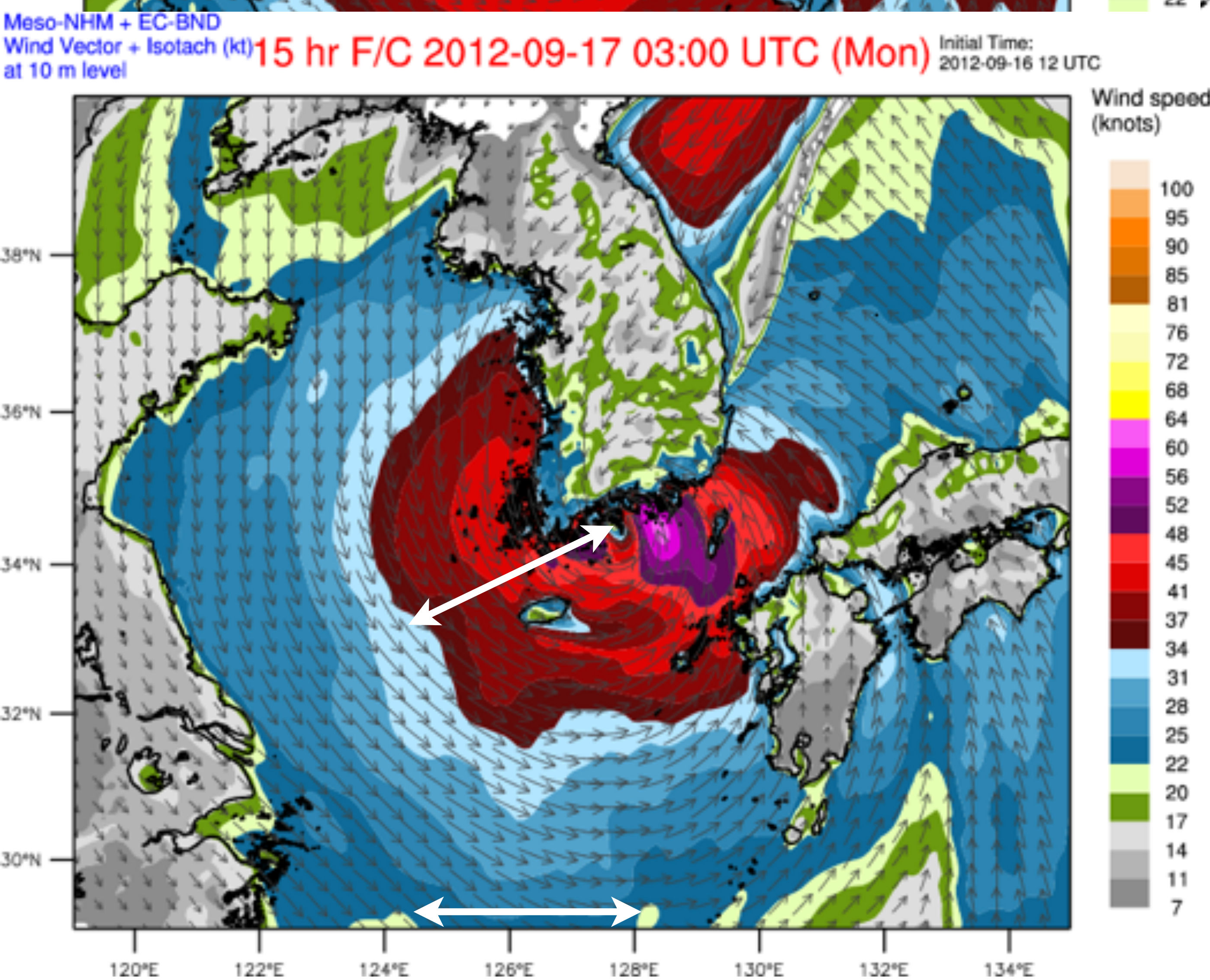
Devastating Typhoon Sanba, which is generating winds of up to 97mph, and triggering blackouts in many homes and businesses is moving in a northeasterly direction and is expected to hit eastern waters later today.

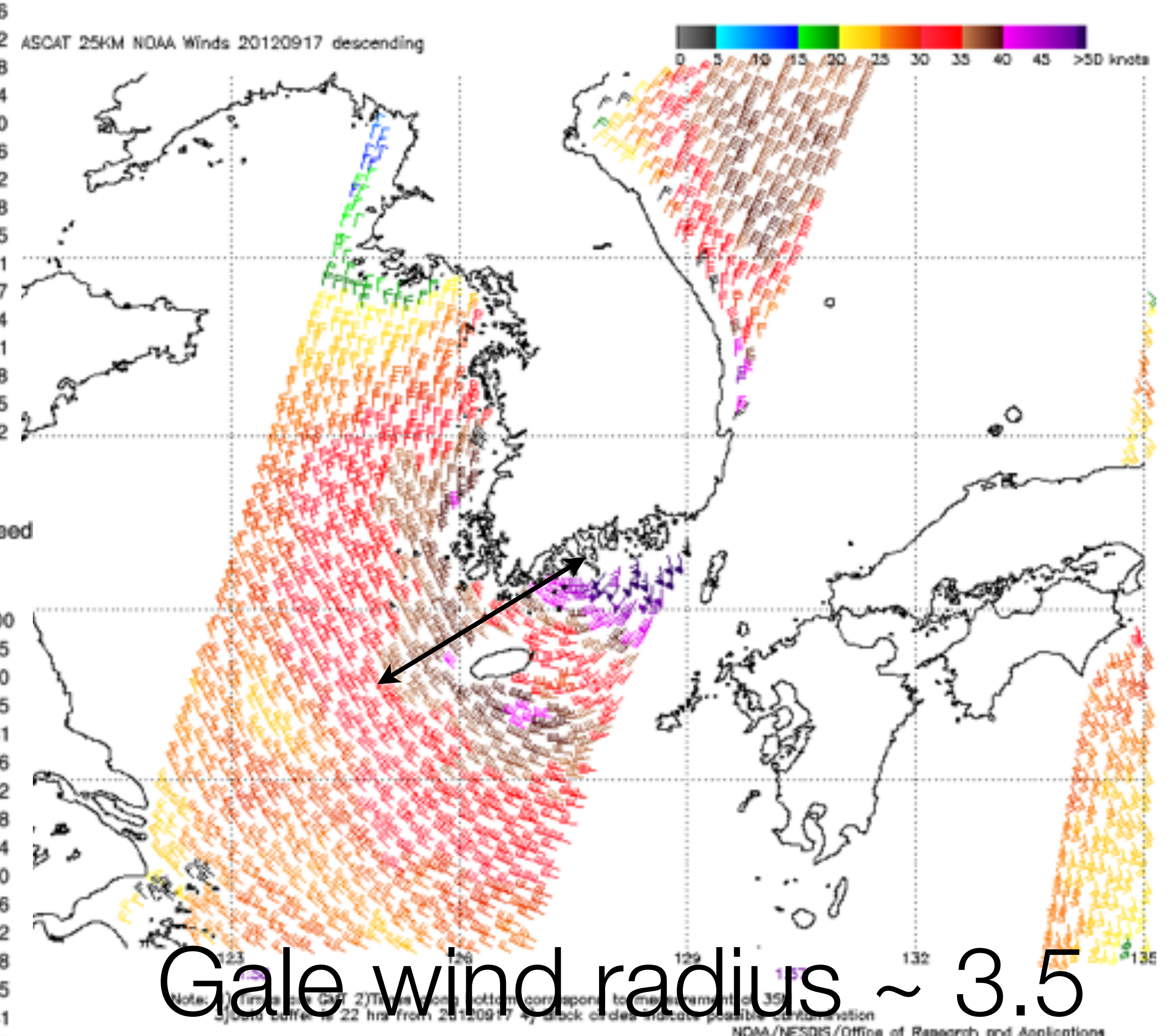
North Korea is not expected to get a direct hit, but the country's eastern areas could see strong rain and wind from the edge of the typhoon, according to South Korean weather officials.



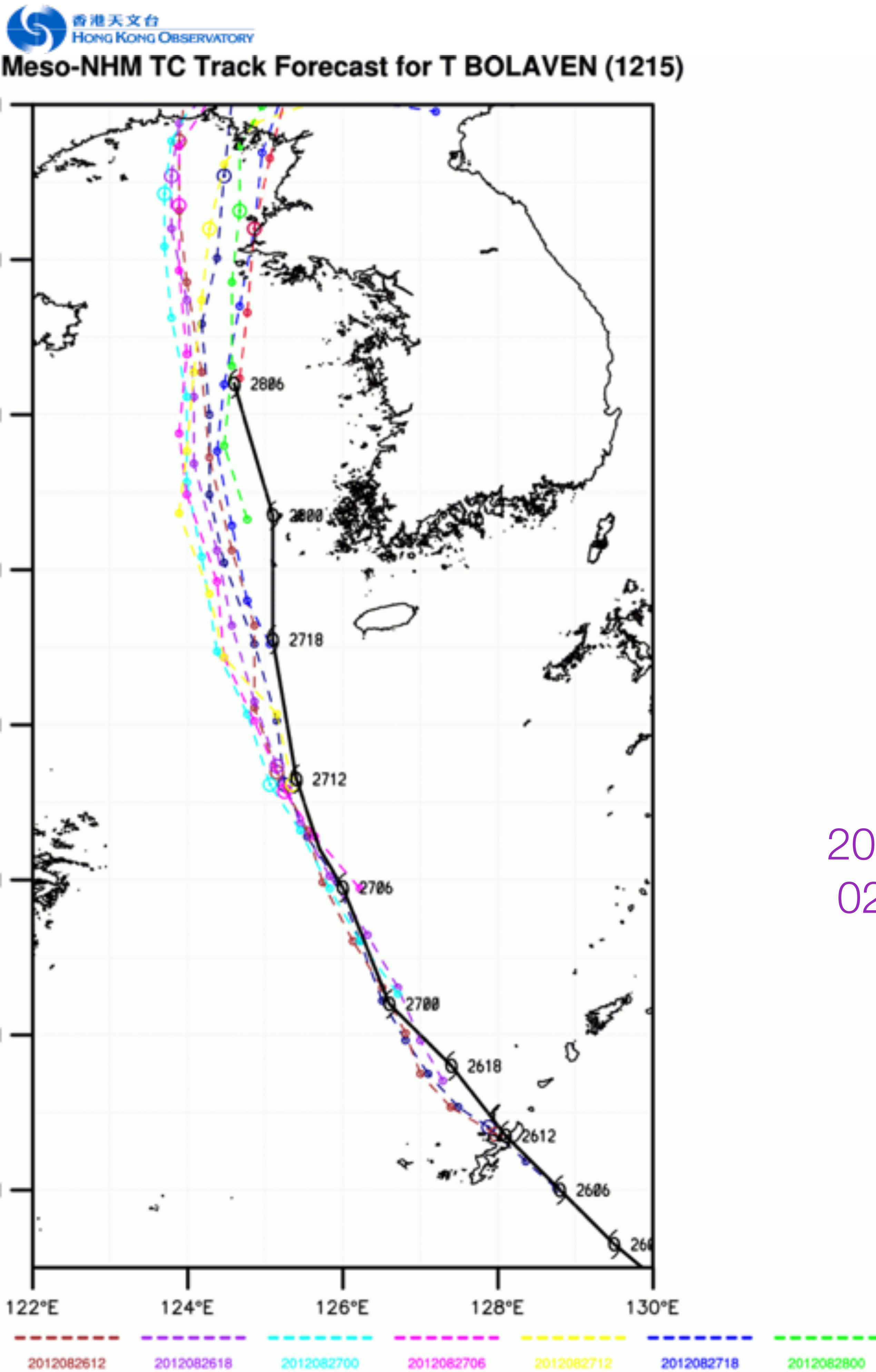
Model consistencies in forecasting of <u>over 81 knots wind (gust)</u> areas hitting southern Korean Peninsula

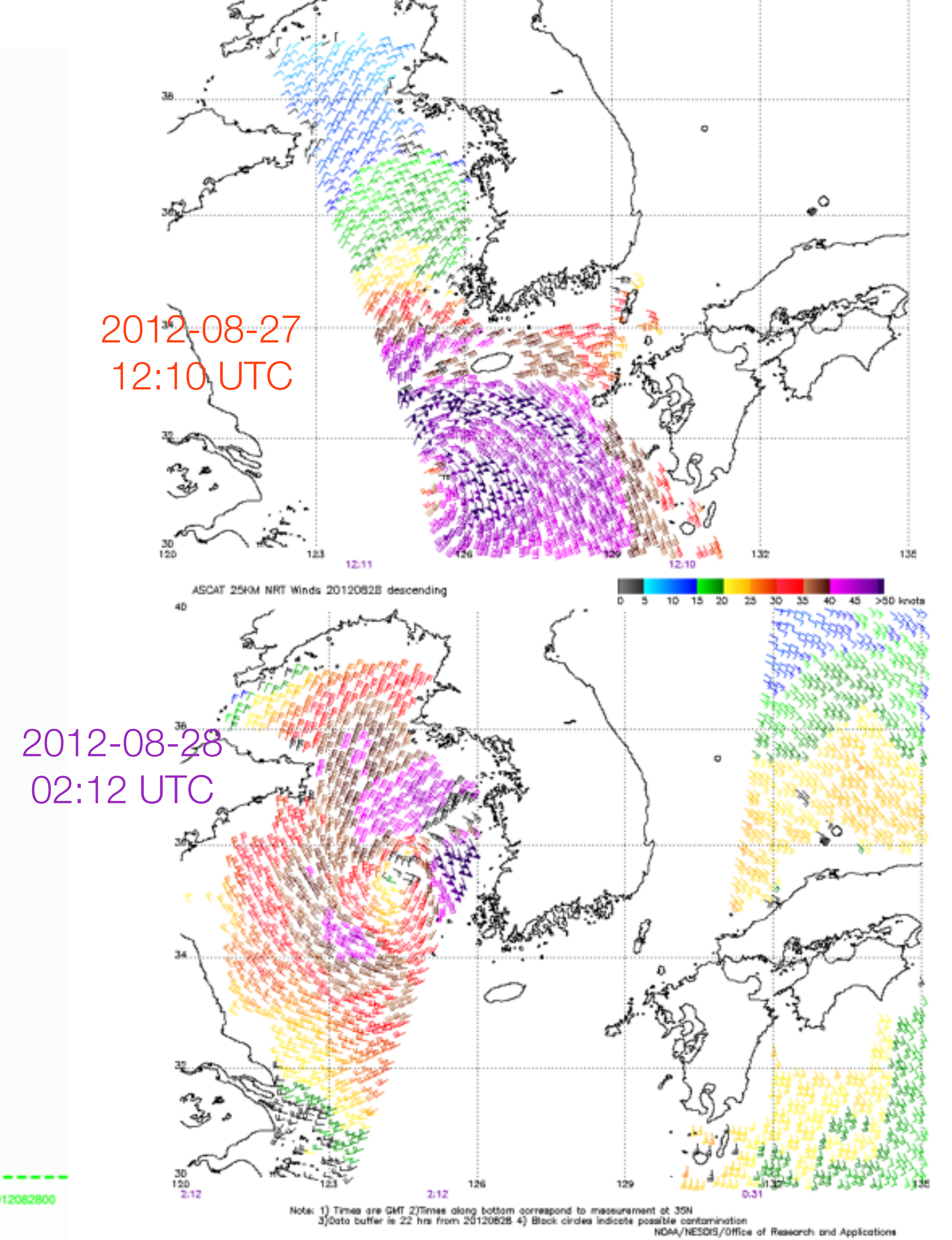




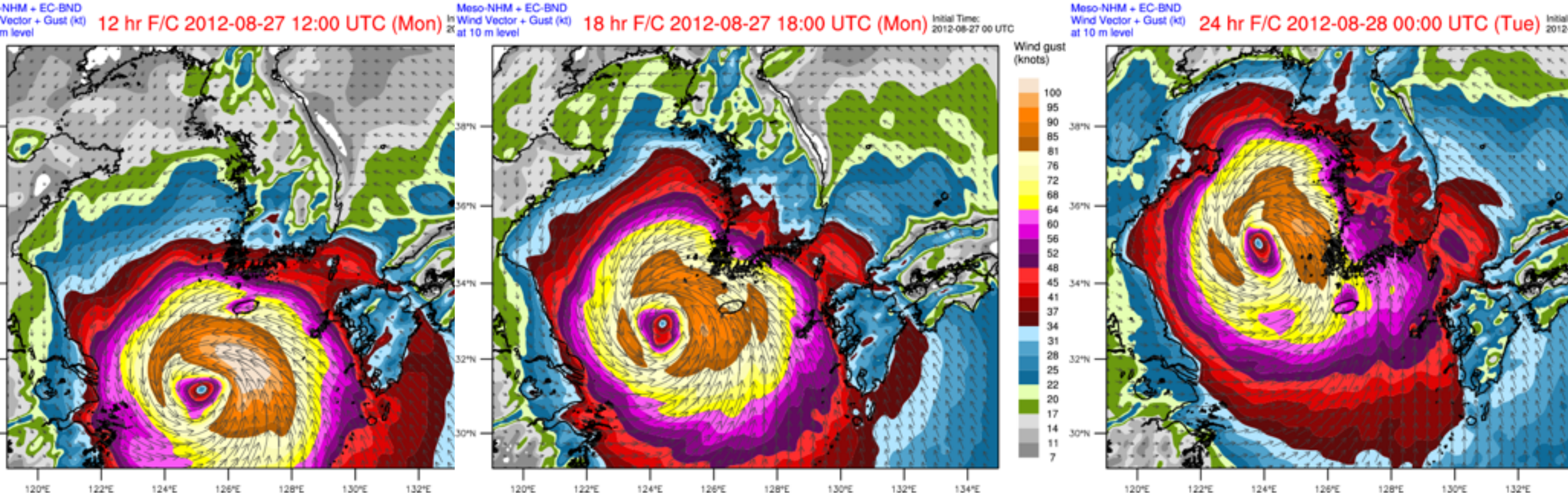


Gale wind radius ~ 3.5 deg

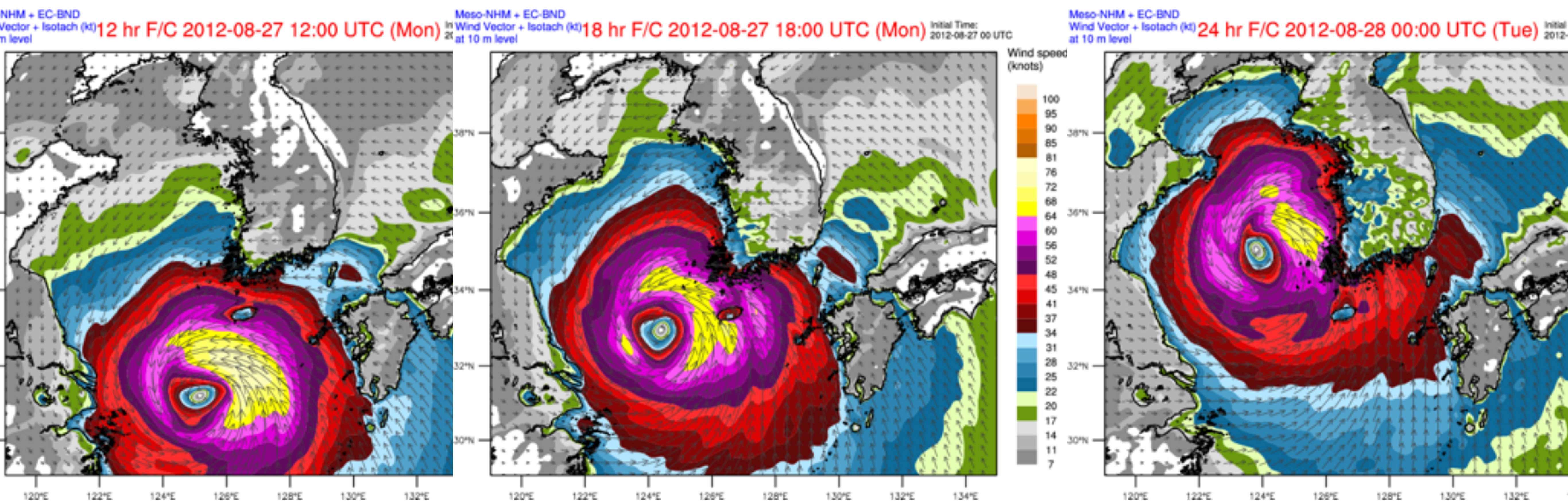

香港天文台
HONG KONG OBSERVATORY
Meso-NHM TC Track Forecast for T BOLAVEN (1215)
2806
2800
2718
2712
2706
2700
2618
2612
2606
122°E
124°E
126°E
128°E
130°E
2012082612
2012082618
2012082700
2012082706
2012082712
2012082718
2012082800


2012-08-27
12:10 UTC
2012-08-28
02:12 UTC
ASCAT 25KM NRT Winds 20120828 descending
0 5 10 15 20 25 30 35 40 45 >50 knots
Note: 1) Times are GMT 2)Times along bottom correspond to measurement at 35N
3)Data buffer is 22 hrs from 20120828 4) Black circles indicate possible contamination
NOAA/NESDIS/Office of Research and Applications

Hong Kong Observatory



12,18, and 24-h forecast wind gust (upper) and wind at 10 m level from 2012-08-27 00 UTC runs



Summary

- Meso-NHM and RAPIDS-NHM have been in operation in HKO since June 2010
  - Atmospheric Integrated Rapid-cycle (AIR) forecast model system
- Targets of AIR/NHM
  - Support mesoscale analysis
  - Enhance quantitative precipitation forecast
  - Tropical cyclones
    - Alternative (and realistic) scenario of weather forecasts over the global NWP model outputs

Thank you very much .